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This Association, as a Body, is not responsible for the statements or opinions of any of its members.

FALL EXCURSION,

SEPTEMBER 14th, 1892.

The Fall Excursion took place at Middleboro, Mass., on Wednesday, September 14th, and was one of the most delightful outings in the history of the Association. The members were received at the depot and driven through the principal streets of the town to the Town Hall where they were received by a delegation of ladies under the leadership of Mrs. J. E. Beals, each member being decorated with a boutonniere. After a collation was served the party visited the pumping station, where the machinery and all surroundings were found to be in excellent order. The party was then driven to Lake Assawampsett where a "shore dinner" was served, which was notable for its excellence. From the lake the party was transferred to the top of Shockley Hill where a fine outlook was obtained of the chain of Middleboro ponds which taken collectively form the largest body of fresh water in the state. After the return trip to the depot a vote of thanks was tendered to all the entertainers in Middleboro who had done so much for the enjoyment of the members of the Association.

This excursion serves as a practical illustration of what a small town can do in the way of entertainment. The programme was carried out by the entertainers with a life and vim which many a more pretentious affair has lacked, and the entire party was enthusiastic over the result. The following is the list of those who were present:

MEMBERS.

Solon M. Allis, Supt., Malden, Mass.; Richard W. Bagnell, Plymouth, Mass.; Lewis M. Bancroft, Chairman Water Commissioners, Reading, Mass.; Joseph E. Beals, Supt., Middleboro, Mass.; Nathan B. Bickford, Supt., W. W. O. C. R. R., Boston, Mass.; Dexter Brackett, Asst. Engineer, Boston, Mass.; George F. Chace, Supt., Taunton, Mass.; E. J. Chadbourne, Supt., Holbrook, Mass.; R. C. P. Coggeshall, Supt., New Bedford, Mass.; H. W. Conant, Supt., Gardner, Mass.; Lucas Cushing, Asst. Supt., Boston, Mass.; Francis W. Dean, Mechanical Engineer, Boston, Mass.; Frank L. Fuller,

Civil Engineer, Boston, Mass.; W. J. Goldthwait, Marblehead, Mass.; Frank E. Hall, Supt., Quincy, Mass.; E. A. W. Hammatt, Civil Engineer, Boston, Mass.; L. M. Hastings, City Engineer, Cambridge, Mass.; Ansel G. Hayes, Asst. Supt., Middleboro, Mass.; Horace G. Holden, Supt., Nashua, N. H.; David B Kempton, Commissioner, New Bedford, Mass.; Patrick Kieran, Supt., Fall River, Mass.: Wilbur F. Learned, Asst. Engineer, Boston W. W., Watertown, Mass.; Eugene P. LeBaron, chairman, Middleboro, Mass.; James W. Morse, Supt. Natick, Mass.; Hiram Nevons, Supt. Cambridge, Mass.; Edward C. Nichols, Commissioner, Reading Mass.; Charles E. Pierce, Supt., East Providence, R. I; Henry W. Rogers, Supt., Haverhill, Mass.; Daniel Russell, Everett, Mass.; Frederick P. Stearns, Chief Engineer State Board of Health, Boston, Mass.; D. N. Tower, Supt., Cohassett, Mass.; Horace B. Winship, Civil Engineer, Norwich, Conn.; George E. Winslow, Supt., Waltham, Mass.; C. J. Underwood, Jr., *The Engineering Record*, New York city; J. G. Lufkin, National Meter Co., New York city; F. E. Stevens, Peet Valve Co., Boston, Mass.; N. F. Ryder, Varnish, Middleboro, Mass.; J. B. K. Otis, Union Water Meter Co., Worcester, Mass.; J. G. Reaser, Walworth Mfg. Co., Boston, Mass.; H. T. Duke, R. D. Wood & Co., Philadelphia, Penn.; H. A. Gorham, the George Woodman Co., Boston, Mass.

GUESTS.

Mrs. L. M. Bancroft, Reading, Mass.; Mrs. J. E. Beales, Middleboro, Mass.; Mrs. N. D. Bickford, Boston, Mass.; Mrs. George F. Chace, Taunton, Mass.; Mrs. E. J. Chadbourne, Holbrook, Mass.; Mr. and Mrs. Dexter, Holbrook, Mass.; Mrs. F. L. Fuller, Boston, Mass.; Mrs. F. E. Hall, Quincy, Mass.; Henry Howard, New Bedford, Mass.; Mrs. D. B. Kempton, New Bedford, Mass.; H. L. Lincoln, Cambridge, Mass.; Mrs. H. W. Rogers, Haverhill, Mass.; Mrs. Daniel Russell, Everett, Mass; Mrs. D. N. Tower, Cohassett, Mass.; Miss Smith, Cohassett, Mass.; E. A. Stevens, Jr., Middleboro, Mass.; A. R. Turner, Jr., Middleboro, Mass.

LAYING A SIPHON UNDER BROOD CANAL, CAMBRIDGE.

BY

JOHN L. HARRINGTON, Foreman, Cambridge, Mass.

I have felt for sometime that many of the annual reports of our departments might be made more interesting and instructive if the Manager or Superintendent saw fit to incorporate into them some account of special work performed by him, as it is not the large but small things we are looking for. With this fact in mind, I make the following description of the laying of a so-called inverted siphon under Brood Canal in Cambridge.

After the disastrous fire which consumed the buildings of the Damon Safe works, an economical opportunity was afforded the city to extend First

street to Main street by taking a small piece of land and building a bridge.

So First street was laid out, and an opportunity given to connect the two easterly extremities of our water system, thereby establishing a much needed circulation; and early in the present year, the Water Board decided to lay a 12 in. pipe, making this connection. It is in this line that the siphon was laid.

The plans were made by City Engineer L. M. Hastings, and contemplated the laying of the siphon under the bridge in place of at one side, for the better protection of the pipe, and in consideration of its cost.

I say inverted siphon, knowing as we all do that no such thing can be; "A siphon is the oldest device for transferring water or other liquids to a lower level over a barrier," and the moment we invert it, it ceases to be a siphon. But the expression being usual, as applied to such work, I so refer to it.

Brood Canal is an artificial channel leading west from Charles River near West Boston bridge. In it the tide rises and falls about 10 feet. On either side is a sea wall, the distance between being 114 feet. The soil is mud on top, with fine sand below.

The siphon is made up of 12-inch cast iron pipes, with the Ward flexible joint for the horizontal part, and the ordinary bell joint for the vertical parts, and stretches across under the canal, within 5 feet of the walls up and through them, the total weight being about nine tons. The pipes of the Ward pattern weighed 1400 lbs. each.

Generally speaking, the form is five sides of an eight sided figure, built that way to give it greater depth at the draw, and less depth at the walls, so as not to weaken them.

Because of this form the flexible joint was used. Otherwise a coffer dam or staging would have been necessary, in either case, at an additional expense.

Preparatory to sinking the siphon a trench was scooped out across the canal, perhaps 20 feet in width and 9 feet below low water, at its greatest depth, this width being necessary, as it seemed best to work the dredger parallel with the sides of the canal, and in this position, the shovel swung at a radius to give that width.

This trench limited our working time to three hours before and after high tide; otherwise the scows were liable to ground on the edge and topple in. We also found it advisable to work quickly, as the action of the water rapidly filled in the trench. A delay of two days, caused by a storm, made necessary the services of a diver, to hoe out the deposit, before the siphon would settle home.

The siphon was put together upon four scows, in two sections, as the time at our disposal made it impossible to do more than one section a day by daylight.

To lay the pipe over the end of a scow as is usual with the flexible joint where the length of pipe to be laid is considerable, and no danger of grounding and dumping the work overboard, is possible, was not practicable in our case.

February 29, two 60 feet scows were brought up and placed parallel within 2 feet ; of each other, and secured in that position.

These scows were of the common pattern and have but a narrow platform on either side, perhaps 2 feet in width, the centre being open to receive mud. Our work was all done on these two platforms and between them. As the weight on these edges tended to list the scows, other pipes were placed on the opposite sides and rolled in toward the centre, when the siphon was let go.

As soon as the horizontal pipes of one section were made up, it was towed out into the river, where it could float, without grounding, until called for. That part of the vertical ends, which were sunk with the horizontal parts, was made up without them.

March 1st the second section was towed out and the following day we intended bringing both sections in, placing them end to end across the canal, making up and dropping the whole into place, but a severe storm came on at this time, and for two days no work could be done. No damage was sustained, and on March 4th the siphon was brought in and with the use of seven derricks was dropped into position. This was just as the tide was turning, so as to give us time to correct any miscalculation, if occasion required. This part of the work was accomplished inside of three days, leaving out of consideration the stormy ones.

It was the work of two days more to extend the ends up and through the walls, and set gates, one on each side of the canal. We were now ready to test, after which the vertical ends were boxed up and filled in with hot coal tar and gravel.

To test we made a connection with the street main, but finding the pressure dropped off, indicating a leak, we subjected the siphon to air pressure and judging from the bubbles appearing on the surface of the water, we located the leaks (for there were two of them) at the joints where the smallest angles were made ; one on each side of the canal near the ends. A diver hammered up the joints, as best he could under the circumstances, and we afterward secured a satisfactory test, though it was deemed wise to put a quantity of oat meal in the siphon and allow it time to soak well into the joints.

It may be inferred the joints were badly run or improperly driven. I personally saw the pipe laid in a straight line. Each joint run without packing of any kind, and no lead escaped from a joint into the pipe, showing the pipes were driven home, and all were properly hammered. I am unable to determine the cause of these leaks, provided we assume the flexible points used were perfect joints. Most of them evidently were.

It ought not to have been, because of any strain, for these joints are specially made to stand such.

Mr. Townsend, the contract diver, described a case where a line of 6-inch pipe was laid with a flexible joint. When the test was applied a leak of considerable consequence was discovered, and numerous ways of stopping it were tried. He finally succeeded by sinking an anchor on the beach, attaching a tackle to it from the end of the pipe, and taking up the slack in the joints.

The finished siphon cost $1,694 89. Following is a list of the items, which go to make up the cost:

New England Dredging Co		$310.00
15,781	lbs. Flexible Joint Pipe at .03½	512.88
26	ft. Cast Iron Pipe at $1.04	27.04
	Boxing	350.00
2	12-inch Elbows at $10.50	21.00
2	12-inch Sleeves at $6	12.00
2	12-inch Tees at $15.65	31.30
2	12-inch Gates at $42.41	84.82
2	Iron Boxes at $4.50	9.00
600	lbs. Lead at .05	30.00
20	lbs Packing at .13	2.60
66¾	Days' Labor at $2	133.50
	Foreman	20.00
7	Days' Teaming at $2	14 00
	Gravel	14.00
11	Barrels Tar	30.75
	Diver Townsend	92.00
		$1694.89

We now have the siphon laid and the pressure is on, and I desire to devote a few moments to an attempt to explain some of the details.

When the siphon was dropped, the vertical ends stood but a few inches above the surface of the water at low tide. As the siphon was dropped at high tide, these ends were not visible, and it was necessary they should stand plumb. To accomplish this we drove a 12-inch wooden plug, one in each end, and into these plugs set a piece of 4-inch joist, long enough to show several feet above the water. By observing these sticks, we regulated the position of things below.

When the siphon was building, it lay between the scows, so the load came on the edges nearest together. When it was raised a few inches that the ropes and planks might be removed. long enough to allow it to drop below the platforms, the tendency was to separate the scows and spread the legs of the derricks. To overcome this, an iron rod was used, bent at both ends, so as to hook around the derrick legs, just over the pipe, one rod to each derrick. Before the siphon was dropped to the bottom, the ropes and planks were replaced, making all secure again. These rods were afterward returned to the blacksmith, and only the labor on them charged.

How to remove the tackles in 19 feet of water and not cut the ropes was the next question. It was done with the use of iron rings, placed around the pipe, one ring for each tackle, and they were left on the pipe.

These rings were of 1-inch round iron, 16 inches in diameter, and to each was attached a strong cord, long enough to reach to the surface of the water after the pipe was sunk, and it was fastened to a wooden float. This cord served to lift the rings clear of the top of the pipe, giving two inches of space, so as to get a hook under it, if occasion required after the siphon was sunk.

To connect these rings with the tackle block hooks, a special hook was made.

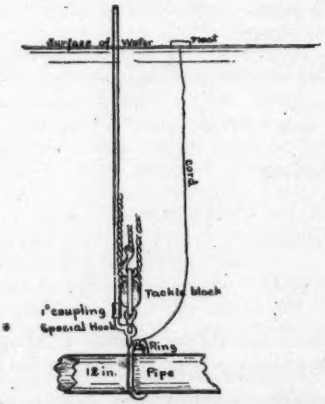
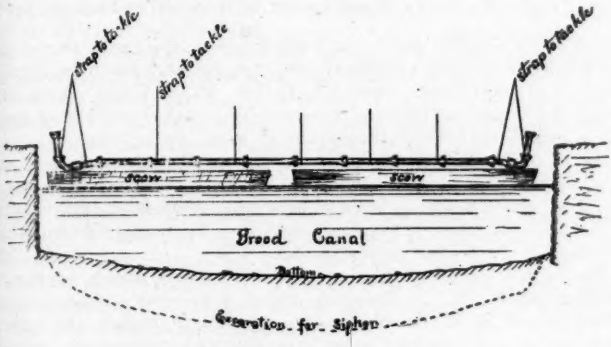


FIG. 1.

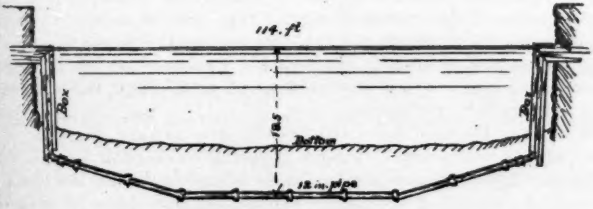
To get an idea of what it was like take two pieces of 1-inch round iron about eight inches long; bend a right angle in each of them; weld one arm of one of these pieces to one arm of the other, and we have one piece (Fig. 1) looking like a section of a short pair of stairs, with two rises and two treads. At the point where the pieces were joined, weld on a small ring, into which the hook of the tackle block is to catch. The lower horizontal arm is to take hold under the rings on the pipe. On the upper verticle arm, cut a thread to take an inch coupling, and you have the device.

Into this coupling a piece of 1-inch pipe was made, the pipe being long enough to reach above the surface of the water, when the siphon was bedded, and was used to remove the special hook with the tackle from the rings at the proper time. This whole arrangement served not only to save cutting the tackles but placed us in such a position, that should it become necessary, from any cause to move the siphon after it had once been sunk, the tackles could be put on again without difficulty, and the siphon moved in whatever direction desired.

Seven of these hooks were required. Long rope straps were used, one to each tackle, and the straps on the two vertical ends were left on.



Siphon on scows.



Siphon in place.

THE EFFECT OF THE AERATION OF NATURAL WATERS.

BY

PROF. THOMAS M. DROWN, Massachusetts Institute of Technology, Boston.

It is a very common belief that water deprived of air will deteriorate in the quality and become unfit for use and that the only way to maintain its purity is to keep it freely exposed to the air. The mountain stream which breaks over rocks and stones is thought to be a good illustration of the intimate connection between the aeration of water and its purity.

On the other hand, it is not generally known that the waters of many deep wells which we prize for their high purity, their clearness, coolness and good taste, contain no air, and have been preserved in this condition in the earth, for aught we know, for centuries. There is clearly a need of a clarification of our ideas on this subject.

Pure water, preserved from contact with organic matter, remains unchanged indefinitely. If exposed to the air it dissolves a definite amount of the gases of which the air is composed—nitrogen, oxygen and carbonic acid—the amount dissolved being dependant upon temperature and pressure. If the pressure is removed, or if the water is boiled, the gases escape, to be reabsorbed when the water is exposed to the air again at ordinary temperatures; but in no sense does the air exert any preservative action on the water or tend to keep it "fresh" or "sweet."

The condition of affairs is, however, entirely changed when water contains organic matter which is capable of undergoing decomposition. The familiar process of the change of organic into mineral matter by decomposition is one of oxidation, and the necessity of the presence of air to carry on this change is well understood. The breaking up of organic matter when oxygen is not present is one of putrefaction, the products of which are usually very offensive.

The analogy between the comparatively slow process of oxidation in nature and the destruction of organic matter by combustion has seemed to justify the inference that we can hasten the former as we can the latter by increasing the supply of oxygen. Acting on this assumption, it is not uncommon in water works practice to aerate the water by causing it to flow over a series of steps, or by forcing it into the air as a fountain, or by pumping air under pressure into the distribution system. Whatever the method employed for aerating the water, the idea behind it is that the water will be thereby purified by oxidation to a degree beyond that which would take place if the water were exposed to the air on the surface only.

During the past two years numerous experiments have been made in the laboratory of the Massachusetts State Board of Health to test this theory of accelerated oxidation, and all the experiments have given negative results. The question, let it be clearly understood, is not one of supplying oxygen to an impure water like sewage, which contains no oxygen, but this: Will an impure water, which contains at all times more or less free oxygen

in solution be purified more rapidly by oxidation if the amount of oxgyen is increased by spraying the water or by pumping air into it; can the natural process of oxidation be hastened by these means? It is to this question that the experiments give a negative answer. If we look for the cause of this failure to hasten oxidation by increasing the amount of oxygen we find that it rests in the inherent nature of the process, a process which is only remotely analogous to the chemical process of combustion. In combustion we have the direct chemical combination of carbon and hydrogen with oxygen, and, by varying the supply of oxygen, we can at will make the combustion slow or rapid. The case is entirely different in the oxidation of organic matter in nature. Here we have to do with the living activity of bacteria, which, in some way not fully understood, causes first the carbon and hydrogen of the organic matter and then the nitrogen to combine with oxygen. This process can only be hastened by increasing the number of bacteria, or by providing more favorable conditions for their activity. Thus we know that the temperature at which bacteria are most active differs with different species, but we have no evidence that, provided some free oxygen is present, the activity of the bacteria of decomposition is in the least affected by its amount. Here the analogy of bacterial oxidation and combustion ceases.

The first series of experiments was made to ascertain whether there was any change in the nitrogen compounds in waters under different conditions of aeration, namely:

(1.) By exposing water contained in bottles to the air of the room.

(2.) By drawing a current of air through the water by means of an aspirator.

(3.) By shaking the water with air in a bottle in a shaking machine driven by an electric motor, the air being renewed from time to time by removing the stopper from the bottle.

(4.) By exposing the water to air under a pressure of 60 to 75 lbs. per square inch in soda water siphons.

The results of the following experiments, shown in Tables I. and II. are given as typical of several that were made:

Table I. — Results of Aeration of Water by a Current of Air Drawn Through the Water in a Flask by Means of an Aspirator,* by Air Under Pressure, and by Shaking the water with Air in a Bottle.

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*The air used for aspiration was taken from outside the building. The air of laboratories where gas is burned contains enough nitrogen in the form of nitrites to vitiate an experiment of this character.

It was found that there was a very small amount of free ammonia taken up by pure water from the air in the cases of prolonged aeration.

First Experiment With Cochituate Waters.
(Parts per 100,000.)

	Free ammonia.	Albuminoid ammonia.	Nitrogen as nitrites.	Nitrogen as nitrates.
Original Sample	.0014	.0182	.0002	.0275
After standing in open bottle for 48 hours.	.0008	.0176	.0005	.0250
After aerating by current of air for 48 hours	.0014	.0170	.0003	.0250
After standing in open bottle for 216½ hours	.0036	.0158	.0002	.0250
After standing 49½ hours and then aerating by a current of air for 167 hours.	.0026	.0156	.0002	.0250
Fourth Experiment with Cochituate Water.				
Original Sample	.0018	.0140	.0002	.0200
After standing 72 hours	.0016	.0152	.0002	.0300
After aerating 72 hours	.0024	.0142	.0002	.0200
After being under pressure of 75 lbs. for 72 hours	.0036	.0150	.0002	.0250

Table II.—Experiments with Cochituate Water to Which a Small Amount of Sewage has been added.

(Parts per 100,000.)

	Free ammonia.	Albuminoid ammonia.	Nitrogen as nitrites.	Nitrogen as nitrates.
Original sample	.0780	.0300	.0000	.0250
After standing 6½ hours	.0720	.0326	.0000	.0250
After standing 42 hours	.0664	.0372	.0002	.0380
After standing 7 days	.0766	.0226	.0002	*.0050
After shaking 6½ hours	.0740	.0294	.0002	.0250
After being under pressure of 75 lbs. for 42 hours	.0584	.0368	.0002	.0260
After aerating 42 hours	.0400	.0402	.0003	.0260

The variations in the amounts of albuminoid ammonia and the nitrates in these experiments are in general too small to have any significance, and fall, in most cases, within the limits of accuracy of the processes used. The loss of free ammonia when the water is aerated is an instance of the driving out of one gas by another. Ammonia cannot be completely removed in this way, but when it is present in considerable amount in a water the effect of aeration by a current of air is very marked. When sewage is thus aerated a very considerable amount of free ammonia passes out with the air.

In some cases the changes in the amounts of nitrogen compounds are

*This decrease in nitrates may have been possibly due to the growth of algae in the bottle.

not easy to explain as the result of any particular treatment. The problem is a complex one. On the one hand we have the tendency of the organic nitrogen to pass into ammonia, and the ammonia to be oxidized to nitrates, and, on the other, the influence of vegetable organisms in directly assimilating the nitrogen of the ammonia and nitrates. Still, the results, as a whole, show plainly that the aeration of water containing nitrogenous matter and ammonia in considerable amount has no tendency to accelerate the oxidation of the nitrogen.

In the foregoing experiments the nitrogen compounds only were investigated. The oxidation of the carbon of the organic matter represented by the albumnoid ammonia would have as a result the formation of more free ammonia; but, as any inference based on the amount of free ammonia might be complicated by its partial removal by aeration, a series of experiments were made to ascertain directly whether any carbon was oxidized by vigorous aeration. In this series only air under pressure was used, and the evidence of the oxidation of carbon was obtained by the "oxygen consumed" from permanganate, which oxidizes only carbon and hydrogen of organic matter, not nitrogen. Should any considerable oxidation of the carbon take place by the oxygen of the air under pressure there would be a considerable reduction of the amount of permanganate used, or of the "oxygen consumed."

The results of these experiments are given in Tables III. and IV. as follows:

Table III.—Experiments on the Aeration of Cochituate Water by Air Under Pressure of 70 Lbs. per Sq. In.

(Parts per 100,000.)

	Oxygen consumed from permanganate.	
	Without pressure, standing in open bottles.	Under 70 lbs. pressure
Original Sample	.452	...
After 24 hours	.421	.488
After 48 hours	.421	.452
After 5 days	.478	...

Table IV.—Experiment on the Aeration of Sewage Diluted with Distilled Water.*

(Parts per 100,000.)

	Oxygen consumed from permanganate.	
	Without pressure, standing in open bottles.	Under 70 lbs. pressure
Original sample (sewage, 1 part; water, five parts)..	.913	...
After 6 days	.888	.955
After 16 days	.682	.700

*The results of the many more experiments in both series will be found in full in the report of the Massachusetts State Board of Health, now in press.

Here, as in previous series, we find that no more rapid oxidation goes on when the air is under pressure in the water than when the water is exposed to the air at the surface. It may be fairly concluded from the above experiments that oxidation of the elements which go to make up organic matter is a process which can not be hastened by offering the bacteria, which are the active agents in the process, an excess of oxygen. Their activity is not stimulated in this way.

This is in accord with the interesting investigation of Dr. A. R. Leeds, who examined the water above and below Niagara Falls and found no difference in the free ammonia, albuminoid ammonia and oxygen consumed after this vigorous aeration. An interesting confirmation of the results of these experiments may also be found in the special report on Sewage Purification (Massachusetts State Board of Health, 1890) in which (pages 730-734) is given an account of experiments to determine the amount of air necessary for a good purification of the sewage by oxidation in intermittent sand filtration. When the atmosphere in the sand of the filter contained from 1 to 3 per cent. of free oxygen the oxidation was as complete and rapid as when 20 per cent. or the full amount of the atmosphere, was present.

Although the strictly chemical theory of oxidation in the aeration of water will have to be abandoned it does not follow that the practice of aeration is not without good effect. It is a well known fact that one soluble gas passed in a current through water will drive out other soluble gases which may be present in it, provided there is no chemical combination between the water and gas. The same effect, is accomplished by exposing water with any gas in solution to an atmosphere of another gas. Thus when we pass a current of air through water containing sulphuretted hydrogen in solution, the latter is completely driven out, and an offensive water becomes entirely odorless. This is not a case of oxidation, for a current of carbonic acid will effect the same result. In the same way a water which has temporarily a bad odor from an excessive development of algae, or infusoria, can be rendered quite odorless by sufficient aeration. Even sewage loses its odor when aerated by a current of air for many hours In these cases the only change effected is the mechanical removal of the soluble gas which is the cause of the odor.

There is another good effect of aeration where it is accompanied by agitation of the water, namely the prevention of the growth of algae with their attendant bad tastes and odors. As is well known it is only in the comparatively quiet waters of ponds and reservoirs that this annoyance from excessive development of vegetable growth is met with. Moving waters are free from this trouble. It seems a not unreasonable explanation of the fact that an excessive growth of algae is sometimes stopped by continuons aeration to attribute it to the agitation of the water.

The most rapid means of aerating water are, first, by pumping air into it under pressure, the excess of air escaping when the pressure is removed second, by breaking it into spray by providing a series of falls, or by means of a fountain jet, or, third, by a fall, in a pipe of similar construction to an injector. But these violent methods of supplying oxygen are not neces-

sary if there is circulation in the water of a pond or reservoir whereby all the water in turn is exposed on the surface to the atmosphere.

On the advent of warm weather in the spring of the year the water of any pond over 20 feet deep may become stagnant at the bottom, and if the water contains decomposible organic matter the oxygen in solution is soon consumed and no more can be obtained from the atmosphere. Under these conditions this stagnant layer becomes very foul from putrefaction. This matter has been very fully studied in the case of Jamaica Pond, Boston, and is described in the report of the Massachusetts State Board of Health on the Examination of Water Supplies, 1890, and also in the forthcoming report for 1891.

But the water in the stagnant layer does not become foul unless there is decomposible organic matter present. Thus, in Basin 4 of the Boston waterworks, which was carefully prepared for the reception of the water by the removal of all soil and vegetable matter, and is supplied with a brown swampy water from a water-shed almost entirely free from population, the water is good at a depth of 40 feet, because the water contains very little organic matter with a tendency to decomposition.

The water is permanently stagnant during the summer months only below a depth of about 20 feet, because it is turned over by strong winds to this depth in ponds of 100 to 200 acres area. But water may be temporarily stagnant at a less depth in the absence of strong winds. In some ponds we have found oxygen to be absent at a depth of 10 feet, and the water to contain much free ammonia and other products of decomposition, which were absent in the layers nearer the surface.

In cases where it would be possible to bring about a circulation of an entire body of water during the warmer months, so that the lower layers would be brought to the surface and stagnation prevented, we would have effective aeration of the water with the prevention of the accumulation of products of decomposition.

In the case of ground water it is now well understood that the more directly from the ground it is supplied to the consumer the more acceptable it is. It needs no aeration. In fact, its storage in open reservoirs results often in the conversion of a cool, clear, palatable water into one which is repulsive to sight, taste and smell.

There is, however, one class of ground waters, not infrequently met with, which are only fit to use after they have been exposed to the air; namely, waters which contain considerable iron in solution in the form of protoxide. These waters deposit iron oxide on standing, owing to their absorption of oxygen from the air. Aeration in connection with settling basins or filter beds, might make waters of this class available for general use.

To resume:

(1). The oxidation of organic matter in water is not hastened by vigorous agitation with air or by air under pressure.

(2). The aeration of water may serve a useful purpose by preventing stagnation, by preventing the excessive growth of algae, by removing from water disagreeable gases, and by the oxidation of iron in solution.

DISCUSSION.

THE PRESIDENT. Prof. Drown's paper has given us a large amount of valuable information, and I would be pleased to hear something from Mr. Stearns upon this subject.

MR. STEARNS. This paper is very opportune, coming from such a source to tell us what aeration can do and what it cannot do, because I think there has been a great deal of doubt on this question in the past. It seems very clear from the paper that in the case of water that has oxygen in it, as all surface waters do, there is really no need of any aeration whatever. Prof. Drown refers to the fact that bad smelling gases in water may be driven out by the introduction of air. I know an instance of this kind where water was taken in Provincetown from a driven well. This water came from a peculiar formation, which had been made by marine vegetation and sand blown in over it, and it had a very strong odor of sulphuretted hydrogen. By putting it in a bowl and stirring it for ten minutes, giving it in this way a free exposure to the air, that odor entirely disappeared, while at first it smelt so strong that a person was careful to get to the windward side of the pump.

With reference to the stagnant water that is always found in the bottom of deep reservoirs and ponds in summer, I have made some attempt in the past to show why it is desirable to take water from the upper layers and not to get down into the stagnant water where the oxygen is used up; but last summer in several places they drew the whole of the upper layer off and then came down to the lower one which was stagnant, and they had to take that. That is, to go into matters which I have before spoken about, the surface layers are continually improving in the summer, because the algae and other growths gradually sink down into the bottom layers where there is no circulation, and where the oxygen soon gets used up by the decomposition of these algae, so the surface layers are all the time improving and the bottom layers getting bad through this putrefactive decomposition. It therefore seems desirable for any one to so plan his storage reservoirs as not to have to use that part of the water which is down more than 20 feet below high water mark, and it might possibly be a question (where it is necessary to draw deeper) whether it would not be desirable to produce a constant circulation through the summer. I don't know, however, as it is a practical thing to do.

With reference to iron in ground waters I understand that it occurs almost always in the vicinity of swamps and places where all the oxygen in the ground is used up by the decomposition of the vegetable matter, and the iron is in a ferrous state and soluble. In cases where it is necessary to use a water of this kind it is very desirable to aerate it thoroughly and filter it or give it a chance to settle before being used as a water supply. In cases where this condition exists to any great extent the State Board of Health has recommended the town to select a source where the iron was not present, thinking this course better than trying to purify such water.

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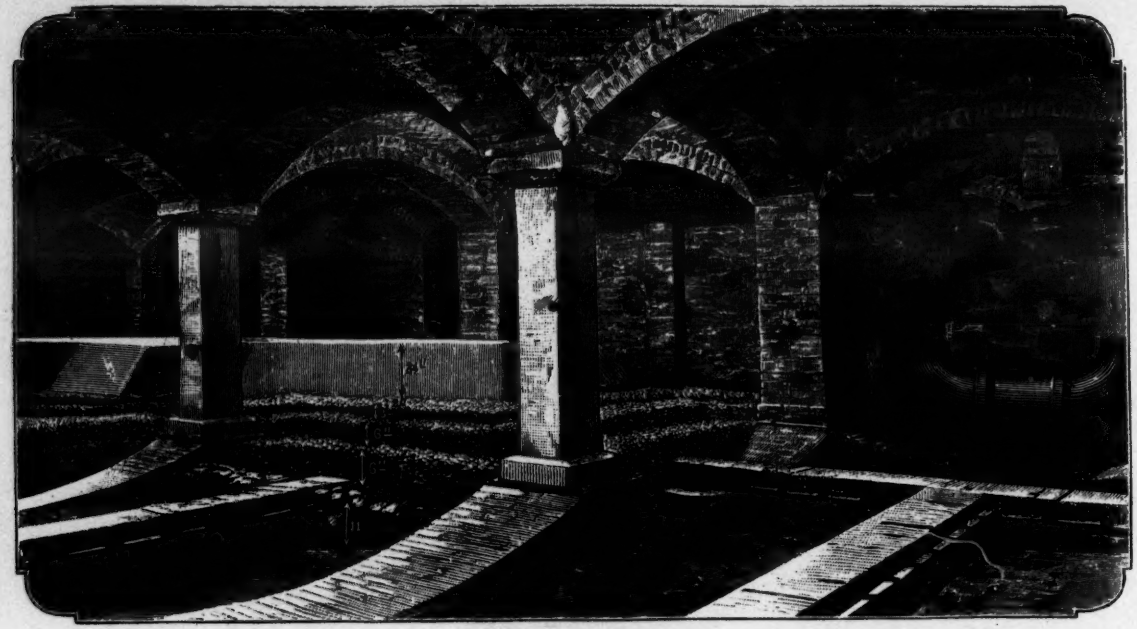

A Covered Filter, Water Works of Warsaw, Russia.
(After Lindley.)

Plate I.

THE PURIFICATION OF DRINKING WATER BY SAND FILTRATION: ITS THEORY, PRACTICE, AND RESULTS; WITH SPECIAL REFERENCE TO AMERICAN NEEDS AND EUROPEAN EXPERIENCE.*

BY

WILLIAM T. SEDGWICK, PH. D., Professor of Biology, Mass. Institute of Technology, Boston, and Chief Biologist to the State Board of Health of Massachusetts.

It has become an axiom, that one of the fundamental sanitary requirements of civilized communities is an abundant supply of pure water. To the requirement of abundance American communities have been quick to respond. The statistics of American water works testify to the energy and spirit which have furnished thousands of our cities and towns with bountiful supplies of water and with water works both extensive and costly.

There is reason to believe, however, that we have given hitherto relatively too much attention to water works and not enough to water. In meeting the requirement of abundance we have done well; but in the equally fundamental and equally important requirement of purity of our water supplies we have too often failed. It is humiliating but it is true tha the sanitary condition of many of our otherwise excellent water supplies is today discreditable to American science, American engineering and American civilization. So long as the water supplies of important cities like Chicago, Philadelphia, Albany, Lowell, Lawrence and St. Louis remain in their present condition so long will they constitute a blemish upon our fair civilization.

A city or town may dig wonderful tunnels; it may build great water works or buy magnificent pumps, but if any or all of these convey impure water from fouled lakes or polluted rivers, if they occasionally deliver to the confiding citizen in his work shop or in his home the deadly germs of disease they must be set down by all sane persons as lamentable failures, because dangerous to the public health.

It is worth our while to inquire how it has come to pass that so many cities splendidly equipped with water works and ably officered, are still supplied with water that is obviously polluted with raw sewage and is shown by statistics to be a carrier of the germs of specific disease. The only explanation that I have been able to discover is the following.

Until lately the selection of sources of water supply has been largely influenced by the belief that impure water quickly, naturally, and effectually purifies itself. Again, we have often failed to foresee the growth of our own or of neighboring populations, and therefore the consequent difficulty of maintaining the purity of natural sources of supply, such as lakes and

* An Address (illustrated by stereopticon), delivered at the Annual Meeting, in Holyoke, Mass., June 10, 1892.

rivers. The latter fact is the more remarkable because as a people we have never failed to proclaim the future greatness of our cities, or the rapid strides of our population. Yet we may well believe that Chicago would have adopted a different system of water supply, if when it began to dig the first lake tunnel it had dreamed of its future greatness. We can easily believe that Philadelphia, Albany, Lowell, Lawrence and St. Louis would have sought other sources or means of supply if when their water works were introduced they had known that the self-purification of rivers is only a half-truth, and that by the use of unfiltered river water they might make typhoid fever virtually endemic within their borders.

We are but just beginning to realize the mischief which a too eager reliance upon the theory of the rapid and effectual self-purification of polluted waters has done. Half truths are often more dangerous than error. We are learning to our cost that in this case we have leaned upon a bent, if not a broken, reed. To show how slow has been the recognition of this fact we need to remember that it is only seven years since a distinguished authority referring to the polluted Mohawk-Hudson solemnly assured the people of Albany, through their Water Commissioners that "There is no reason why the city of Albany should not continue to use this water," and reaffirmed his earlier opinion that "The most careful examination of the water has failed to reveal anything to sight, taste, smell or analysis, which can be considered as throwing the slightest suspicion upon the purity of the Hudson, or its fitness for supplying a perfectly wholesome beverage for the citizens of Albany." It was only in December last that a prominent Chicago newspaper with astonishing ignorance or effrontery boasted of the magnificent water supply of that city, asserting that Chicago has at its doors an unlimited supply of the purest water in the world, to be had for the mere cost of pumping. Six weeks later the same newspaper was imploring its readers to boil the city water before drinking it, and childishly ascribing the revelation of the natural consequences of its use to an imaginary eastern jealousy.

After making all allowance, however, for the unfortunate and undue influence of the self purification theory, and for our strange inability to forsee and provide for a probable growth of population of which we were at the time loudly boasting, much still remains chargeable only to gross carelessness or indifference. The probable pollution of the Chicago water supply was officially pointed out by the State Board of Health of Illinois in 1884 and further demonstrated in 1886, but no remedy has yet been applied. Typhoid fever has long been excessive in Philadelphia; but so far as I am aware, no steps have yet been taken to remedy the evil, although there is every reason to attribute the excess chiefly to the use of unfiltered polluted river water.

Lawrence languidly discusses but has not yet begun to remedy the dangerous condition of her water supply, polluted only nine miles above the intake by the sewage of 80,000 people and further up by that of as many more. Meantime typhoid fever ravages the city, claiming relatively more victims from Lawrence than from any other city of the state. Lowell, also proceeds but slowly towards purification of her water supply which is only somewhat less objectionable than that of Lawrence. Yet it can no longer be claimed that

the dangers of polluted drinking water are doubtful or imaginary. The citizens of Paris are officially warned when the water of the Seine is about to be supplied to them. The citizens of Chicago, Lowell and Lawrence have all been warned against their public drinking water in its unfiltered condition, and we cannot doubt that those of many other cities ought to be so warned.*

The eminent statistician Korosi has recently shown in a very valuable paper that typhoid fever has prevailed to an unusual extent in Buda-Pesth within the past four years. The water supply of Buda-Pesth is drawn from the Danube, a highly polluted source. Some portions of the city receive the river water purified by sand filtration; other portions get the Danube water entirely unfiltered. Comparing certain of these districts Korosi was led to conclude, upon purely statistical grounds, that, in proportion to the population, typhoid fever was twice as abundant among those using the Danube water raw as among those who used it after sand filtration. His natural conclusion is that the substitution of filtered for unfiltered polluted waters with a view to the reduction of typhoid fever mortality, is much to be desired.

We have met tonight, however, not so much to discuss the fact or the origin of the unfortunate conditions which exist in many American cities and towns, as to consider what we can do to abate them. Here, I think, we may profit by European experience. Civilized European cities are few in which raw river water or unfiltered sewage-polluted water of any kind, is delivered to the people as their source of supply for drinking purposes. I believe that the time is at hand when in America, also, we shall cease to use unpurified water for drinking and must turn for relief to some process of purification; and I venture to predict that within the decade we shall witness the establishment of numerous and extensive municipal systems of water purification by some form of sand filtration.

The purification of water from the sanitary standpoint is the most difficult kind of purification.

The principal natural methods contributing to the sanitary improvement of water are *sedimentation*, *storage* and *filtration*. Light, temperature, pressure and electricity have their effects but an impure water is purified in nature chiefly by *settling*, for the bacteria have weight, and at least in some stages of their development, tend to settle; by *storage*, which has a double action shortly to be explained, and by *filtration* through the earth.

Storage has immense sanitary value and has not been hitherto sufficiently appreciated. There is good reason to believe that a water otherwise good but containing disease germs might be rendered wholesome and pure by simple storage. Under such conditions some of the bacteria settle to the bottom and eventually perish; some are destroyed by light, but the disease germs, being apparently in water somewhat short-lived, perish. It is also a fact that living bacteria largely disappear in the pipes of a service. To these facts we must look for the explanation of the limited infectiousness in some cases by water

*Since this address was made Chicago has begun to dig an immense sewage canal, which when completed, will probably improve her water supply. Lawrence has adopted a system of sand filtration and Lowell has appropriated $100,000 towards improvement of its public water supply.

obviously badly polluted with raw sewage. I am convinced that if Lawrence for example pumped directly into the pipes, as Chicago does, her death rate from typhoid fever would be far greater than it is. A recent writer has urged that sewage polluted water be drunk as soon as possible after its pollution, in order to avoid the disagreeable putrefactive phenomena which might ensue; but if what has just been said is true it is plain that to do this is to invite disaster; it is the same kind of advice which would lead us to strain out a gnat and swallow a camel.

The sanitary value of storage is not yet, by any means, as well known as it deserves to be. Storage involves the element of time, time gives opportunity for change, and the changes which storage tends to effect in polluted water are often of the highest sanitary significance. There is no evidence that disease germs multiply in ordinary natural waters. Such evidence as we have, both from experiment and experience, indicates on the contrary, that disease germs die out more or less rapidly in good natural waters. Time, therefore, is an all important element in the sanitary improvement of infected waters, and we may safely say that infected water like wine improves with age. Here is one element of great sanitary value in storage. It may be called the vital element. Another element is sedimentation. This is mechanical instead of vital in its action, but is unquestionably of very great value in the purification of water. The germs of disease though microscopic, are material, and they are subject to the law of gravity. They are also easily dragged down by heavier masses in their settling, and a muddy water may on standing purify itself to a remarkable degree merely by settling. Thus storage, by bringing in the element of time, allowing the disease particles to die out, and by favoring sedimentation, is of immense sanitary value, while settling basins for muddy waters not only clarify, but to a greater or less extent also actually purify the water which passes through them. It is probably for this reason that St. Louis has fared as well as it has hitherto. Particularly valuable is the storage of flood waters because in times of flood infectious material is more rapidly transported than usual from point to point. The great water companies that so ably supply the wants of the largest city in the world make a special point of the storage of the flood waters of the Thames and the Lea, and that they are right in doing so the vital statistics of London amply demonstrate.

I know that there is another side to the storage question. I know that stored waters exposed to the light are apt to become troubled by unsightly and ill-smelling growths. I know that if the latter provoke disgust or nausea in the consumer the sanitary value of storage is justly called in question. But in spite of these drawbacks, which cannot be overlooked, it is still true that storage, by favoring sedimentation and giving time for specific disease germs to die out, is, nevertheless, from the sanitary standpoint, of great value in the purification of polluted waters.

To recapitulate: *sedimentation* is a valuable means of the purification of water and has its sanitary value in removing disease germs from flowing or standing water. St Louis has great settling basins in which the muddy water of the Mississippi is settled. Here in addition to their own tendency to fall by gravity the removal of the disease germs is probably greatly aided by the

falling particles of mud which drag them down. *Storage* is of great sanitary value, first by giving time and opportunity for sedimentation and secondly by giving time for the disease germs to die out. New York doubtless derives much sanitary advantage from her great storage system. Neither of these methods of purification, however, is entirely trustworthy. If the storage is too brief some germs will survive; if the sedimentation is incomplete the effluent from the settling basins will still be unsafe.

There is another natural method, however, which is more common and more trustworthy. This is *filtration* through the earth or sand. I do not need to do more than to remind you of the pure spring which pours from the earth, germ free, its sparkling water originally the rain or snow but since filtered through deep layers of the earth; or of well waters which in spite of their occasional privy and barn-yard origin are, as a rule, free from the germs of disease. Yet these are really filtered surface waters, and in their history we may discover the secret of the more extensive purification of great bodies of water, such as lakes and rivers. The fouled waters of barn yards if run off upon the farmer's meadow become purified. Even the more solid stable manure thickly spread upon the field if committed to the earth and turned under by the plow readily disappear. These examples and the more familiar results of burial show how the earth—the living earth, as it has been well called—teeming as it is with bacteria and other micro-organisms, purifies organic matters, even when they are in the fluid state. But apart from this vital action, earth, and especially sand, is an excellent strainer. Ordinary loam is too fine and soon gets clogged, but sand especially after it has become partly clogged is a capital filter, for it works rapidly and yet so effectively as to retain even the bacteria in the applied liquid. Long before the immense purifying capacity of sand filtration could be demonstrated scientifically it had been proved by experience. Wells sunk in the earth have been known from the earliest times, and have often given excellent water though sunk in regions in bad sanitary condition. When in 1850 the dangerous pollution of the Thames and the London water supply was demonstrated by Dr. Hassall, by means of the first systematic microscopical examination of a public water supply ever attempted, the remedy applied was storage and sand filtration. The steady improvement in the sanitary condition of London, which is today the wonder and the envy of the world, is due in no small measure to the protection afforded by her now very extensive system of sand filtration. I am myself persuaded that in scientifically conducted sand filtration we have a complete solution of the problem of a safe and sanitary water supply. I am ready to agree with Fraenkel, the professor of hygiene at Marburg and Piefke, the accomplished engineer of the Berlin-Stralau water works when they affirm that:

I. *Every surface water, before it is used for drinking purposes, should be freed from all infectious substances.*

II. *For this purpose, whenever large quantities of water are to be treated, sand filtration is at present the most convenient and effective method.*

It is not claimed that all waters need to be filtered, but when a city or town is so unfortunate as to be obliged to use a polluted source of supply there can be no question whatever as to the requirements of modern sanitary science; the water must first be freed from infectious materials. For this purpose there is nothing better known to sanitary science at present, than scientifically conducted sand filtration.

It is said that sand filtration was first introduced at Chelsea, near London, by James Simpson in 1839. At the time of the celebrated microscopical examination of the London water supply by Dr. Hassall, in 1850, the water supplied to London was indeed "filtered" by the companies, but so badly that it was scarcely strained, for Dr. Hassall found fish and many smaller objects in the filtered water. After much debate and many inquiries a *Water Act* was passed for London in 1852 which prescribed effectual filtration and storage of the London water supply, to be in operation in 1855, regulated the charges and made other arrangements between the citizens and the eight water companies. The results obtained were so good that the rules then adopted have been followed upon the continent, and the English practice has since served as a model here, as in other branches of sanitary science, to the rest of Europe and to the world. Reserving for the end of this paper a more complete account of the English practice as exemplified in London, let us turn first to the purification of the water supply of the German capital, Berlin. This city has now a population in round numbers of one and one-half millions and it has probably the best examples of sand filters to be found on the continent. Berlin is supplied from two sources, one a lake, Lake Tegel, and the other a river, the Spree, which, below the intake, passes through the city. We may first describe the older establishment, that at the river, known as the Stralau Water Works, under the able administration of C. Piefke, whose studies upon the theory and practice of sand filtration have placed him among the very first of European sanitary engineers. I am personally indebted to Herr Piefke for his courtesy in offering me every facility to study the operation of the Berlin-Stralau Works on the occasion of my visit to them in 1891. I have also his permission to make use of his published accounts of his work.

SAND FILTRATION OF THE PUBLIC WATER SUPPLY OF BERLIN.

(A.) THE STRALAU WATER WORKS.

The general location and plan of the filters which purify the water of the Spree are shown on Plate No. II. The position of the two intakes is shown at *a* (the older) and at *b* (the more recent). From a the water flows by gravity to the pumps along the line indicated. From *b* the water is drawn directly by the pumps. From these it passes in a common main along the lines *ll* to the several filters, but as it is impossible to adjust the pumps to the varying demands of the filters this supply main ends in a small supply or compensating (*Vorraths*) reservoir shown on the northern border of the filters. When the pumps are not working the supply for the filters is drawn from

this. Its capacity is 11,000 cubic meters (2,906,000 gallons.) This reservoir with the open filters No. I.-IV., near by, represents the oldest portion of the plant. Originally it served in good measure as a settling basin, but as new filters have been added, this function has gradually diminished until now the daily output of the plant far exceeds the capacity of the reservoir and it serves as little more than a regulating or compensating reservoir of unfiltered water. It is but just to say that owing to the enormous growth of Berlin the present system is said to be decidedly overtaxed. More filters should be added immediately, and I am informed that steps have been taken looking to this end. Since 1873 the Stralau works have consisted of 37,067 square meters (about nine acres) of filtering surface, arranged in eleven independent sections or basins. They may be worked separately or together. The normal maximal output of the whole plant is placed by Piefke at 60,000 cubic meters (15,850,000 gallons) every 24 hours. But sometimes, on special occasions, it has been as much as 70,000 or even 80,000 cubic meters (18,000,000—21,000,000 gallons.) Three of the filters (Nos. IX.–XI.) having a combined area of 9,000 square meters (2.2 acres) are covered, to guard against severe and prolonged cold weather. In winter the daily consumption (from this plant) sinks as a rule to 30,000 cubic meters (7,925,000 gallons.) It ought to be said, at this point, that the newer Tegel Water Works (to be described beyond) supply a comparatively fixed quantity of filtered water to Berlin, summer and winter alike. The extra demand of the summer falls, therefore, largely upon the older works at Stralau, and these are at times plainly overtaxed, giving too rapid filtration with incomplete purification.*

The filtered water is drawn off beneath the several filters by under drains which convey the water to a reservoir for purified water (*Reinwasser*) placed at such a depth as to receive the effluent by gravity. (See Plate II. and Plate V. Figs. 1 and 2.) This has a total capacity of only 2,200 cubic meters (581,000 gallons.) The sand washing establishment, which at Berlin, is regarded as a most important feature is located in the angle between filters No. VI. and No. IX. (Plate II.) The engine and boiler houses, the Office, and the dwellings of the resident engineer, etc., are shown in section on the street front (Plate II.)

The intake located at *b* on Plate II. is shown in elevation, plan, and sections on Plate III. and requires no special remarks. *The filters* are shown in sections (transverse and longitudinal) on Plate IV. Fig. 1 shows a longitudinal section through the under drain. Fig. 2 is a cross section showing the (central) under drain, the overflow waste pipe and the general arrangement and construction of the filters. For the details of the construction I must refer the reader to the original paper of Piefke. Suffice it to say that the bottom must be water tight and the sides strong enough to support the pressure of the enclosed water. Those at Berlin-Stralau are laid upon clay (*Thon*) covered with concrete (*Beton.*) (See Plate IV., Fig. 2.) Fig. 6

*These and the following data are taken from Piefke *Aphorismen uber Wasserversorgung* II. Zeit fur Hygiene, VIII., 1890.

is a section through one of the covered filters (Plate II., Nos. IX.-XI., showing the piers, arches and the openings to admit light during the process of cleaning the filter. Piefke remarks, however, that for cleaning, artificial light is on the whole to be preferred to the scanty daylight which can be admitted in this way. The actual filtering materials used at the Stralau works and resting upon the concrete, are as follows, beginning at the top:

Fine Sharp Sand	22 inches
Coarse Sand	2 "
Fine Gravel	6 "
Medium Gravel	5 "
Coarse Gravel	3 "
Small Stones	4 "
Large Stones	12 "
Total	54 inches

It is interesting to compare this construction with that of the London filters shown in the tables beyond (see Appendix pp. 4-7) as well as with the sand filters of Zurich and Warsaw (p. 115) and the Berlin-Tegel works (p. 113.) Piefke expressly states that he does not consider a greater depth of sand to be of much advantage, provided that the sand shall be sharp, and he believes that more time and trouble is often spent upon these details of the actual filtering materials that is necessary. The under drains connect directly with the lower layers of the filter so that while the water sinks vertically through the sand it flows laterally through the coarser underlying layers. From time to time the filter must be drained for cleaning. If it is not desired to drain it completely but only for scraping the very surface, the valve shown at *v* in Plate IV., Fig 2, and connecting with the overflow (*u*) may be opened. If it is desired to drain the filter thoroughly another valve known as the "sand cock" (*Sandhahn*) shown in elevation in Fig. 4 and in section in Fig. 5 may be opened. I must pass over many interesting details of the actual management of the filters which are fully described by Piefke in the paper referred to. Numerous automatic devices for detecting the precise conditions at any particular moment, and for aiding the superintendent, have been introduced at Berlin; but for these also I must refer the reader to the original paper.

The ordinary process of filtration is conducted as follows: After a filter has been worked for a time it is found to have become clogged and allows the water to pass through only very slowly. The arrival of this time is shown by an automatic tell-tale float (w) seen in section in Fig. I. If, with the valve *k* closed, this float rises but very slowly it is clear that in spite of a high pressure of the supernatant water (h) only a little passes through the sand. The filter is then described as "dead" and must be cleaned. It is therefore drained and a gang of men is set to work on it with broad thin shovels, or with special "scrapers." A plank track is laid on an incline down into the basin and the scrapings are taken away in wheel barrows to

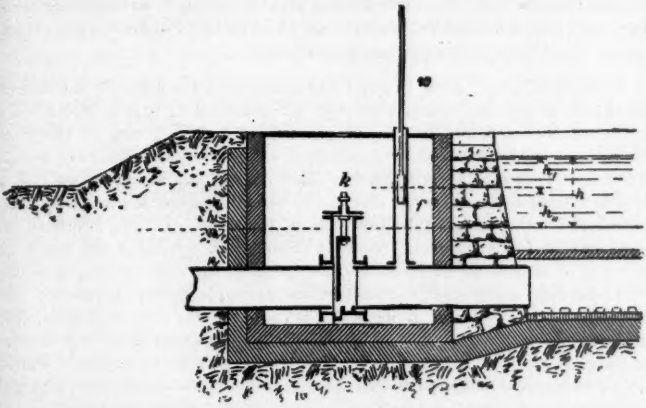

FIG. 1. Tell-tale float w in use at the Berlin-Stralau Water Works. The output of the filter, regulated by the gate k, remaining constant the height of w will indicate roughly the degree of resistance, or clogging. (After Piefke.)

the sand-washing house. At the time of my visit a gang of perhaps thirty men was cleaning a filter. Only the uppermost layer of sand and the dirt deposit upon it was removed. This dirt deposit or *Schmutzdecke* is extremely interesting. In Berlin I found it to consist of a thin membranous layer of a greenish brown color and so well defined that it could be easily peeled off in flakes from the sand below very much as a moistened postage stamp can be peeled from a piece of paper to which it has become partially attached. The sand below the *Schmutzdecke* was clean and white to a very noticeable and striking degree, so that it was obvious that only the *Schmutzdecke* required to be removed. Carefully detached by the scrapers it was drawn up into little heaps of a peck or a half bushel each and these were carried away on the wheel barrows to the sand washing establishment. Once the *Schmutzdecke* has been removed and the life of the filter is restored, the sand is smoothed, the filter slowly filled from below (with clean water) to drive out all air and prevent fissures or channels, and the whole covered with unfiltered water to the depth of about 3 or 4 feet through the inflow pipe. (Plate IV, Fig. 3.) Meantime the outlet is kept closed so that the supernatant water stands quietly upon the sand and is allowed to settle. This is a point of much importance as the consequence of this set ling is the formation of a delicate membrane or new *Schmutzdecke* upon the clean sand. After a time, varying with the demands upon the plant, the effluent is allowed to escape, fresh unfiltered water flows upon the filter and filtration proceeds. At first it is, of course, rapid and comparatively imperfect, but as the membranous deposit (*Schmutzdecke* thickens, it grows slower and yields a

better effluent. The filtration continues with increasing head and diminishing rate until the *Schmutzdeckce* becomes almost impervious when the filter is said to be "dead" and once more ready for cleaning.

By the kindness of Herr Piefke I was able to examine carefully the *Schmutzdeckce* both *in situ* and microscopically. It consisted of much brown amorphous matter (zoogloea), numerous filaments of algae giving to the whole its dark greenish tinge and its firm felted or membranous character, besides particles of woody fibre, debris, etc. The smooth and almost slimy feel of the membrane appeared to be due chiefly to the algae and the zoogloea. The membrane was perhaps 1-8—1-16 inch in thickness. I have described the *Schmutzdeckce* (surface deposit) in some detail both because I was much impressed by its well defined character and position and also because, according to Piefke, this membranous deposit is the principle factor in efficient sand filtration. One who sees it as I saw it (towards the end of August, 1891) upon an open but "dead" filter cannot help perceiving that such a micro-membrane must indeed play a most important part in continuous filtration. From its peculiar composition and semi gelatinous character, it must be highly effective in the detention of all suspended particles of whatever kind, including bacteria. When the *Schmutzdeckce* is so well defined as it usually appears to be at Berlin the sand below it looks bright and fresh. At the Stralau works the depth of sand may well be thought to be of secondary importance, the real filter being the micro-membrane. Whether it is always of so little importance may be more open to question

Naturally, at Berlin, the scraping is so arranged as to remove as little sand each time as possible. Gradually, however, the sand layer grows thinner and after a time it must be replenished with new (or washed) sand to the original depth. This happens about once in two years, and requires considerable time. Even the ordinary scraping requires that the filter shall be out of connection for several days. At some seasons scraping is required (in Berlin) very often (once a week) but in winter very seldom (once in two or three months.) The Spree is not muddy like the Mississippi but at times is very unclean and in summer contains vast quantities of certain algae which are particularly troublesome, making an almost impervious "felt" through which the water moves only very slowly.

The Sand Washing. This is done at Berlin because it is found to be cheaper than to import new sand. The position of the sand washing establishment is shown on Plate No. II. Some of the details of the apparatus employed are shown on Plate No. VI. Fig. 1 shows the ground plan, and Fig. 2 the section. Fig. 3 is the revolving drum in which the sand is washed. Fig. 4 is the section A-B on Fig. 1. Figs. 5 and 6 shows sections of a centrifugal pump. This is a very interesting portion of the work but space forbids me to enter upon it in detail. Piefke states that all of the filters are cleaned perhaps twenty times annually, and that about $\frac{1}{2}$ of the filtering material has, therefore, to be washed or otherwise renewed, yearly.

(B.) THE BERLIN WATER WORKS AT LAKE TEGEL.

To keep pace with the growth of Berlin and the increasing consumption of water a new and separate establishment was in 1877 added to that at Stralau and located on the other side of the city, by the southern shore of Lake Tegel. The following account of the Tegel Water Works is drawn almost exclusively from the admirable account of the works given by the resident engineer, G. Anklamm, and published with additions, as a reprint from *Glaser's Annalen fur Gewerbe und Bauwesen, Bd. XIX. Berlin*, 1886. I have ventured to reproduce from this two of Anklamm's admirable and instructive plates. (See Plates VII. and VIII.) Plate No. VII. shows the general location and plan of the Tegel works with some details of construction of the (covered) filters. Plate No. VIII. shows the several parts of the sand washing apparatus.

Originally the attempt was made to obtain a supply of pure water without filtration from the shores of the lake by sinking there a number of wells. These at first yielded an excellent supply, but after a time the water deteriorated owing to the growth in the wells and in the mains of an iron-bearing bacterium *Crenothrix*. This grew to such an extent in the Tegel water supply as to constitute what has been called "The Berlin Water Calamity." To obviate the difficulty Commissions were appointed, investigations were made, aeration and other means of relief were attempted, but without avail. At length about 1883 sand filters were established to treat the water taken from the lake and these, ever since their installation, have yielded an admirable effluent. When they were first put in operation the mains and service pipes contained an abundant vegetation of *Crenothrix* but little by little this disappeared in the presence of the filtered water. The area of the four larger filters is in round numbers 2500 square meters (27,000 square feet) each, that of the six smaller ones 2000 square meters (21,000 square feet.) The total filtering area is about 22,000 square meters (236,700 square feet or between five and six acres. The normal yield of the filter is placed at three cubic meters of water or each square meter of filtering service for twenty-four hours or roughly at 3,000,000 gallons per day per acre. Seven of the ten filters are usually running at once and serve to furnish the requisite quantity of filtered water. The other filters, three in number, serve as a reserve and also for use in the summer time, when the life of the filters is shorter. The filters are all covered, and in order to keep a temperature as low as possible in summer, they are covered with a layer of earth forty to seventy centimeters thick; this layer is covered with grass.

The filtering material consists of three layers. The lowest is about thirty centimeters thick, of rounded granite stones; upon this there rests a layer about thirty centimeters thick of coarse clean river gravel free of sand and upon this a layer about sixty centimeters thick of medium coarse sand. The average diameter of the sand grains is about $\frac{1}{4}$ of a millimeter. Before the material is placed in position it is carefully cleaned from clay and dirt by special washings. Each filter is fitted with an under drain, with feed pipes, etc. The filter is filled as at Stralau from below in order to drive out the air

particles contained in the sand. This filling must be done slowly for otherwise air will remain in spite of it, and will interfere with the successful operation of the filters by forming during its escape, canals, through which organisms can penetrate into the under layers of sand or gravel.

After the filter has been operated for some time a gelatinous layer (*Schmutzdecke* of Piefke) is formed of such imperviousness that each square meter of surface will no longer furnish as much as three cubic meters (800 gallons) of water in twenty-four hours. When this time has arrived the filter must be scraped, but before the supply is cut off the feed valve is opened wide for a few minutes in order to clean out the feed pipe, and wash away the snails, mussels and deposits of dirt, etc., which accumulate in it. In some cases it is said that as many as twelve hectoliters (several bushels) of snails and the like have been washed out of a single feed pipe. After the valve has been closed and the water has sunk to a depth of fifty or sixty centimeters upon the filter the outflow valve of the under drains is also closed, and the water still upon the filter is run off through the waste pipe. The thin layer of dirty sand to the depth of ten or fifteen millimeters, ($\frac{1}{3}$—$\frac{1}{2}$ inch) is then removed by means of broad sharp shovels, and wheeled off to the sand washing machine. After removing this portion of sand the filter is once more filled with water from below, and set in operation. As a rule, however, this is not done at once; whenever the demand for the filter is not too great it is allowed to rest after cleaning for some time, in the belief that those particles of the dirt deposit (*Schmutzdecke*) which have penetrated unto the lower layers will be oxydised under prolonged contact with the air. In order to facilitate this operation, special attempts are made to secure a certain circulation of the air in the filtering materials. The life of the filters is naturally comparatively brief in the summer months. While it rises as high as eighty days in the winter, it sinks in midsummer, at the time of the so-called "water blossoming," not infrequently as low as ten days. On an average for the year, it is about thirty days. Replenishing with new or clean sand occurs comparatively seldom, and only after the sand layer, originally sixty centimeters thick, has been gradually worn down to thirty centimeters.

The regulating apparatus at the Tegel filters is of great interest; and for the orderly management of the filters is extremely important. It will be seen at a glance that a new filter, as yet unclogged, will offer much less resistance to the passage of the water than an older filter more or less clogged that is, covered with the *Schmutzdecke*. It becomes necessary, therefore, to work an old filter under greater head, and in order that the output shall remain constant, this head must be gradually increased. Special devices to accomplish this end, have been introduced by Henry Gill, Esq., chief engineer of the entire Berlin water supply, by W. H. Lindley of Frankfurt, and by others. Some of these will be described beyond.

I have entered somewhat at length into descriptions of the Berlin filters because they are probably, on the whole, the most carefully planned and most thoroughly studied of any filters on the continent. I may now briefly refer to a few other continental sand filters.

SAND FILTERS AT WARSAW, RUSSIA.

The source of the public water supply of Warsaw is the river Vistula. The water is first run into settling basins, and then upon the filters. The capacity of the filters is about 2.4 cubic meters per square meter of surface, every twenty-four hours. Plate No. I. at the beginning of this paper shows the arrangement of one of the (covered) filters at Warsaw. It will be seen that upon eleven inches of stones, there are six inches of smaller stones, above these six inches still smaller, and upon this layer three inches of coarse gravel, covered by two inches of fine gravel, and the whole surmounted by two feet of fine sand. The passages for the filtered water are shown as spaces between the bricks on the right of the figure. The feed pipe is also shown on the right. At Warsaw it is not customary to wash the sand, as at Berlin (and many other places) fresh sand being found to be cheaper. At Warsaw a filter of 2100 square meters area, was scraped by fifteen men in ten hours, and replenished with new sand by the same number of men in four days. The depth of water upon the filters at Warsaw is kept at 1.2 meters.*

SAND FILTERS AT OPORTO.

Sand filters have been provided for Oporto by *the Compagnie generale des eaux* of Paris. The water is taken from the river Souza. The arrangement of the filters is as follows: The supporting layer consists of stones (large) .15 m., stones (small) .15 m., upon which come first coarse sand .10 m., and fine sand at the top .20 m., making a total of .60 m. The total area of the filters is 1190 square meters, with a normal depth of water of .90 meters. The filters yield on an average 13 cubic meters of water per square meter for twenty-four hours. This system is said to be open to much criticism, probably from its slight depth of sand and high rate of filtration.

SAND FILTERS AT ZURICH.

In consequence of an extensive epidemic of typhoid fever in Zurich in 1884 which was traced to the pollution of the public water supply, a water commission was appointed and prepared a report recommending the installation of a system of sand filters. They advised that water should be taken from the lake (Zurich) at least 200 meters from the shore, and filtered upon sand filters at the rate of six to eight meters (vertical water column) per day. Inasmuch as the requirement of the city was only about 20,000 cubic meters daily, they estimated that a filter area of 3000 or 3500 square meters would be sufficient, This enormous rate of filtration was recommended because of the comparative initial purity of the lake water. It was recognized, however, that extra land should be secured, so that by extension of the plant even with increased consumption the rate need not exceed more than three meters

*For a more complete account of the Warsaw filters and a full and admirable statement of the problem of the purification of river waters for drinking purposes, see W. H. Lindley, *Vierteljahr. fur Oeff. Gesundheitspflege*, 1890, p. 191. Also, an abstract in this Journal, Vol. 5, p. 33, 1890.

per day. In December, 1885, three of the five filters were in operation, and in the following August the fourth and fifth were added. The combined area of the five filters was 3500 square meters. For extension of the plant space was reserved to the extent of 75,000 square meters. Filters number one, two and three are covered ; numbers four and five are open ; all five have the same area with about 672 square meters of effective surface. The filtering material lies upon a solid foundation covered with two layers of brick, and consists from below upwards of the following layers : Five to fifteen centimeters of coarse gravel, upon this ten centimeters of garden gravel carrying fifteen centimeters of quite coarse sand, which is surmounted by eighty centimeters of fine sand. The regulation of the rapidity of filtration is accomplished for each filter separately. When the head or difference in level between the filtered and unfiltered water reaches sixty to eighty centimeters cleaning of that particular filter generally takes place. Cleaning consists in draining off all the water and scraping away the uppermost sand layer with iron shovels to the depth of about two centimeters. Experience shows that only a thin slimy layer (*Schmutzdecke* of Piefke) covers the otherwise clean sand and that this layer is only a few millimeters in thickness. After cleaning, the filter is filled from below with filtered water and once more filtration proceeds. The water which first comes through after cleaning is, however, rejected during this early period and the dirt carried up from the sand by the water after filling and which consists of floating particles of slimy material, is removed as far as possible by letting it run off from the top before filtering begins. In 1887 the cleaning was necessary, on an average, for the covered filters every forty-eight days. As a result of these periodical scrapings the layer of fine sand gradually grows thinner, and when it has sunk so that it is only fifty centimeters in thickness, it is either replenished with clean sand up to eighty centimeters or it is taken out altogether and replaced by a fresh sand layer of the original thickness. This renewal of the filtering material did not become necessary until after the end of 1888.*

SAND FILTERS IN ROTTERDAM.

The city of Rotterdam takes its water supply from a tidal stream, the Maas. Into this stream the sewage of the city also flows. By the situation of the intake and the time of taking in water for filtration, most of the danger of sewage contamination from Rotterdam itself is supposed to be avoided. The Maas, however, is by no means a pure source of supply, and it is often, if not usually, very muddy. The water is first passed into large settling basins to which it flows by gravity. From the settling basins it is lifted by pumps and afterwards flows upon a series of sand filters. Owing to the limited capacity of the works, and to the large consumption of the city, the water is not allowed to stand in the settling basins as long as is considered desirable and the filtration is far more rapid than the superintendent regards as proper. The effluent is now clear, bright and entirely unobjectionable in appearance, and has never

*The foregoing statements are taken largely from *Bertschinger, Wirkung der Sand Filter in Zurich*, 1889. See also *Journal fur Gasbeleucht. und Wasser versorgung*, 1891, p. 684.

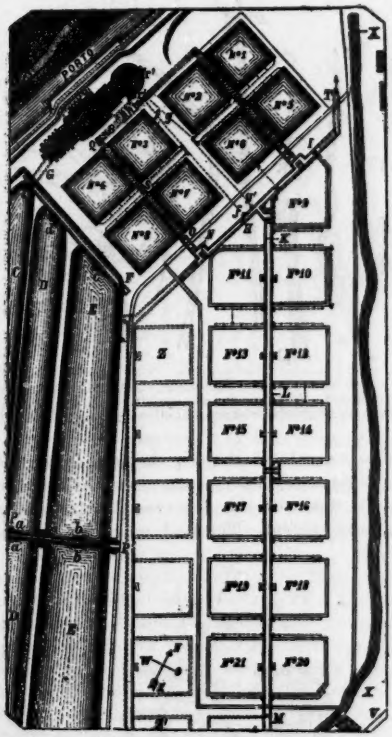

FIG 2. The Sand Filters of Rotterdam, Holland. Nos. 1-8 the older filters. Nos. 9-20 the newer filters. *C, D, E*, settling basins. The pumping station is shown on the border of the canal (Port.) To it water is drawn from the settling basins, and from it water flows to the several filters. (After DeVries.)

caused complaint in the city until a few years since, when the whole system became filled with the much dreaded "pest of water works" *Crenothrix*. This produced complaint, and such a deterioration in the water as to excite the greatest anxiety on the part of the pbulic as well as of the officials. Professor DeVries of Amsterdam has published a valuable account of the investition made by himself and other members of the commission which sought to discover the cause of the evil and a remedy for it. Professor DeVries concluded that the imperfect settling, the excessively rapid filtration, and the existence in some places beneath the filter of old wooden beams, etc., all taken together allowed a sufficient quantity of organic matter to pass into the mains to support a luxuriant vegetation of *Crenothrix*.

I visited the works at Rotterdam in the summer of 1891, and it was obvious to me, that in comparison with the sand filters at Berlin, those at Rotterdam were insufficient and overworked. I am unable to give exact figures as to the

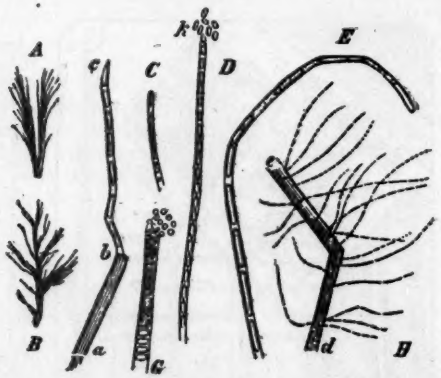

FIG. 3. *Crenothrix Kuhniana.* An Iron-bacterium. *A, B,* flocks or clusters of the plant as it comes from drains or filters. *H,* single threads growing from an older encrusted thread. *C, D, E, F, G,* various stages in its growth and reproduction. (After DeVries.)

depth of the sand, the intervals of scraping, the rate of filtration, the daily yield, etc., but the general construction of the sand filters was similar to that of the Berlin filters. It was noticeable, however, that here the well defined *Schmutzdecke* of Berlin was absent. The sand appeared dirty to a consider-

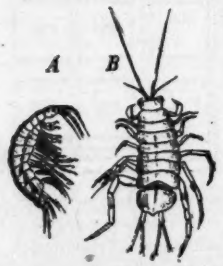

FIG. 4. Small Crustacea which occurred in great numbers in the filtered water at Rotterdam during the Crenothrix calamity. (After DeVries.)

able depth and there was every evidence of overworked filters treating a water originally much worse than any that I had seen. I am under great obligations to Mr. Vogel, the engineer, in charge who showed me every courtesy.*

Enough has now been said of actual sand filters on the continent but as to their operation and their efficiency something may still be said. In

*For a full account of the *Crenothrix* Commission see De Vries's paper, of which an abstract (in English) was published by me in the *Technology Quarterly*, Vol. III., p. 338, 1890.

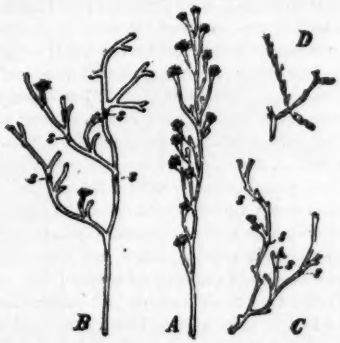

FIG. 5. Moss-like animals (*Bryozoa*) growing in abundance in the conduits of unfiltered water at Rotterdam. (After DeVries.)

September, 1890, there occurred at Brunswick the annual meeting of the German Public Health Association. At this meeting the subject of sand filters for municipal water works was fully discussed by Fraenkel, the distinguished bacteriologist, and Piefke, the accomplished Resident Engineer in charge of one division of the water works of Berlin. The Stralau Water Works as has been shown above are managed with great skill by Piefke, and consist of an elaborate system of sand filteration, the water being taken from the river Spree. Professor Fraenkel and Engineer Piefke incited by an epidemic of typhoid fever which broke out in Berlin in 1889, had come to the conclusion, after careful experimentation upon artificial filters with special bacteria including some of the germs of disease, that contrary to the general belief, it was possible under certain circumstances for disease germs to find their way through sand filters like those in use in Berlin.* Impressed by the importance of their results they formulated the following conclusions which they made the text of special addresses at the Public Health Association meeting just mentioned :

I. Every surface water before it is used for drinking ought to be freed from all infectious materials.

II. For this purpose in all those cases in which large quantities of water have to be treated, sand filtration is to be regarded as at present the most practicable and the most satisfactory method.

III. The operation of sand filters is not, as has been widely assumed always entirely trustworthy and under all circumstances satisfactory. A sand filter is not a germ tight apparatus ; but by intelligent manipulation it is possible to reduce this defect to a very insignificant quantity.

IV. To accomplish this end there are necessary :

(*a.*) Good raw material (unfiltered water) as little polluted as possible.
(*b.*) A low rate of filtration.
(*c.*) Uniform action of the filter.
(*d.*) Rejection of the effluent at the beginning of a new period of filtration.

*See *Technology Quarterly*, Vol. III., p. 69, 1890.

These theses were ably defended by Fraenkel and Piefke at the meeting, but as might have been anticipated, aroused vigorous opposition. Up to this time it was apparently a common belief among the water superintendents and engineers in Germany that sand filters necessarily removed completely or detained, all of the suspended matters of the unfiltered water not excepting the bacteria. It was with this idea that the Zurich filters were established and Bertschinger believed that the few bacteria in the effluent from these filters had come from the stones, the under drains and outlet pipes, and not through the filter. His ideas probably well represented the state of opinion among water engineers in Germany, up to the time of the experiments of Fraenkel and Piefke. They were supported also by the sanitary experience of London, and by English experience in general, for it had been found unquestionably true, that filtration was a great sanitary safeguard; but until the experiments of Fraenkel and Piefke no one in Europe had undertaken to discover, by an application of special cultures of known bacteria to sand filters, whether these could, or could not, be discovered in the effluent.

The experiments of the State Board of Health of Massachusetts made in 1889, and published in 1891, were the first experiments of this kind ever made, and they proved conclusively that bacteria may, under special circumstances, pass through sand filters operated intermittently. The experiments of Fraenkel and Piefke were the first which demonstrated the same possibilities for continuous filters.

The allegation that sand filters might not be an absolute surety against the passage of disease germs, aroused a vigorous debate at the meeting referred to in September, 1890, and met with strong opposition. It was urged more or less effectively that the experimental filters of Fraenkel and Piefke, having been made of wood, and the same filter having been run at different rates, their conclusions were based upon abnormal conditions and were untrustworthy. Piefke has since repeated the experiments under conditions adapted to meet these objections, and has obtained results confirmatory of the earlier experiments. The truth seems to be that sand filters if well managed are a complete sanitary safeguard, but that they require intelligent management to produce the highest results. The experiments of the State Board of Health of Massachusetts, at the Lawrence experiment station have been conducted for a longer time, and with greater care than any experiments elsewhere, or hitherto, and these show conclusively that the results of Fraenkel and Piefke are probably sound. A sand filter is not necessarily a germ tight apparatus, but it is entirely possible to construct and operate sand filters in such a way as to render filtered water safe for domestic use and for drinking purposes.

The address of Engineer Piefke at the meeting referred to* is full of interesting matter concerning sand filtration. He begins by saying that one of the indispensable requisites for success is that the rate shall remain constant, and not depend upon the variations of the consumption during the day. We may get an excellent illustration of the range of this variation in

*The report of this part of the meeting is very interesting and I have drawn largely upon it in the preparation of this paper. It is to be found under the title:—"*Filteranlagen fur Stadtische Wasserleitungen*," in the *Deutsche Vierteljahr. fur Oeffentliche Gesundheitspflege, Bd.* 33, 1891.

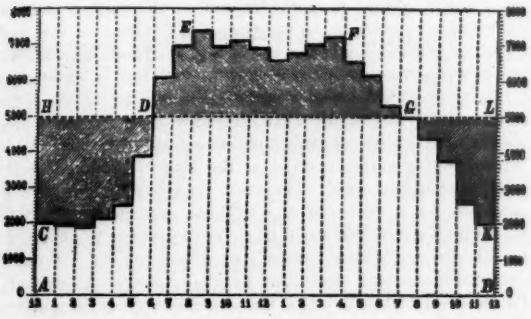

FIG. 6. Hourly consumption of water in Berlin, August 21, 1889. The ordinates indicate cubic meters; the abscissas indicate hours, beginning on the left at midnight. The average hourly consumption (5000) is shown by the horizontal dotted line. (After Piefke.)

consumption if we follow hour by hour the history of the water supply of a great city, on any particular day. In Berlin for example the daily consumption from the two water works (Tegel and Stralau) on the 21st of August, 1889, was 120,000 cubic meters or 31,701,600 gallons. The average, therefore, was 5000 cubic meters or 1,320,900 gallons per hour. The actual consumption per hour varied, however, so much that at midnight it fell 64 per cent. below the average, and during the day it rose about one-half above it. The greatest consumption was between 8 and 9 a. m. and 3 and 4 p. m. The smallest between 2 and 3 o'clock a. m. These variations in their range and distribution can be conveniently followed by the help of the diagram (Fig. 6) which is self explanatory. It follows obviously, that the filters must supply in the night too much, and in the day too little water. It therefore becomes necessary to introduce between the filter and the point of consumption, a reservoir in which the excess filtered during the night, can be reserved as a store for use during the day, the time of maximum consumption. This reservoir may be called the compensating reservoir.

For Berlin, under the conditions prevailing at that time, Piefke estimated by an examination of diagrams such as we have just given, that a compensating reservoir of at least 25,000 cubic meters (6,604,500 gallons) actual capacity was required. In fact the Berlin reservoirs actually hold more than 30,000 cubic meters (7,925,400) gallons and consist of three quite independent sections, so that if one of them needs to be thrown out of connection, the other two may still suffice. Piefke recommends that the reservoir for filtered water should be covered, not only to avoid disturbance through the accumulation of ice in winter but especially to exclude light. In filtered waters exposed to the light various algae and other organisms

flourish and affect more or less unfavorably by their growth the water which has been so carefully purified.

Piefke next considers the proper operation of the outflow and inflow of sand filters. There appears to be no special difficulties in the regulation of the inflow, by the watchman for if the filter receives by mistake at any time too much water the excess can escape through the overflow pipe. (See Plate IV. Fig. 2, *u*) More complex is the management of the effluent in prescribed quantities; this requires the assistance of hydrometric apparatus. Let us suppose that a filter of two thousand square meters area is required to work throughout a certain period at the rate of one hundred vertical millimeters (4 inches) per hour. This will regularly furnish two hundred cubic meters per hour. When it is possible to measure and control at any instant the filtered water flowing off it becomes possible to adjust the filter to its duty. A very convenient method of measuring the water is the one in which it is allowed to flow off out of a spacious tank, through a horizontal slit in a vertical wall. The slit should have, in proportion to its width, an insignificant height. The quantity of water which escapes through the slit, depends upon the height of the water above the upper border of the slit. This we may call the head. Different amounts of head naturally represent special amounts of effluent. If the height of the water above the slit is fixed then it is evident that the hourly discharge of water will always be the same. For different quantities of effluent, corresponding head can be computed, and after this has been once done a scale can be prepared, which, fixed in position, shall instantly show at what point the water level must be in order to obtain a certain quantity of water in a unit of time.

Use is made of this principle in an apparatus which has been much employed for several years under the name of the "Gill" regulator and which is shown on Plate V., Figs. 3 and 4. From the covered filter shown on the right of the figure, filtered water passes through the underdrain *c*. Under the gate house, at *s*, can be seen the slit through which the water flows out freely; a few centimeters above this is the water level computed for the normal or desired rate of filtration; it is plainly marked upon a scale, and for control there is a float which rises and sinks in a tube and carries by a chain over a pulley an automatic pencil. The indicator must not leave the place computed for it, if the filtration is to be constant. A new and more serviceable form of Gill's regulator permits the filtration and supply to be brought very accurately into relation with one another.

The Gill regulator works satisfactorily and permits the operation to go on at any prescribed rate of filtration, but its use pre-supposes intelligent service on the part of a watchman. As this may be regarded as an objection we may turn, says Piefke, to the consideration of automatic regulators. An example of these is that devised by Lindley (see Fig. 7) for the recently constructed filter works at Warsaw. Lindley provides each filter with a walled but un-partitioned gate house. The filtered water rises in this to the proper height and carries a heavy float. Firmly fixed to the latter is

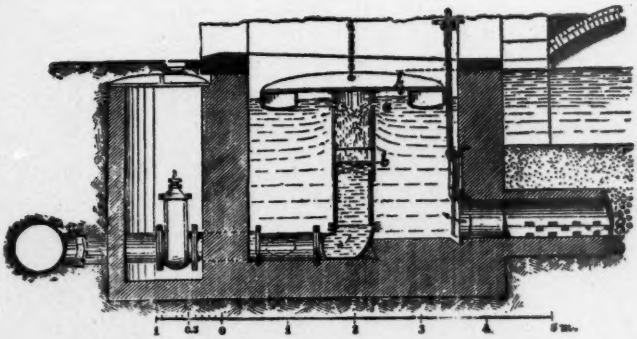

FIG. 7. Automatic regulator employed by Lindley, at Warsaw. The (covered) filter is shown with its underdrain, on the right. For details consult the text. (After Lindley.)

the telescopic tube *b* closed at the top. This naturally shares in all vertical movements of the float, rises and sinks as this does and thus moves up and down over the fixed tube below, which is open at the top and is also shown in Fig. 7. On account of its fixed weight, the float sinks always to the same depth in the water whatever may be the height of the water level in the gate house. If now below the level of the float, we make two elongated slits or openings in the wall of the tube, these will keep at a constant depth beneath the surface of the water, and always allow the same quantity of water to flow off into the tube. Any variation will occur only in case the slits themselves are changed, which is effected by an external moveable ring.

For the maintenance of an even working of the filter, it is required further, that for every portion of filter surface, which for cleaning or any other reason, is thrown out of operation, an equally large area shall be provided as a substitute. The size of the reserve surface involves difficulties which constitute one objection to filtration. Since by cleaning the filter there is removed every time a thin layer of sand, and the sand layer gradually grows too shallow it must after long use become unfit for further operation, and has to be replenished; a task which usually demands several weeks. For this reason also reserve filtering areas should be provided. The surfaces which are provided are usually found successively in different stages of preparation; a part is being cleaned; a part is being worked; and a part is being supplied with fresh sand. Theoretically one may say that the reserve surfaces provided should be three times of the actual filters. Their proportion to the active surface is, however, not constant, but can be discovered only by experience; diminishing obviously with the rapidity of filtration. The objection brought against a low rate of filtration is mainly the financial

one. In his recent paper, Lindley has made valuable statements concerning the cost of construction of filter plants. He gives especially the cost in Berlin and Warsaw, and concludes with the following facts; estimates carefully corrected give for a large establishment of covered filters having 48,000 square meters of filtering area in round numbers 67 marks or 84 francs ($16.75) per square meter. A similar computation for open filters with the same materials and the same price for labor, showed that these would cost about 45 marks or 56 francs ($11.20) per square meter; that is two-thirds as much. The covering of filters thus means on the Continent an increased cost of 50 per cent. Lindley quotes the actual cost of the Berlin filter at Stralau at 64 marks, and at Tegel 68–72 marks per sq. meter. He cites early English experience as indicating a cost of $10–$13 per sq. meter, everything included.

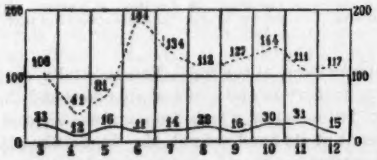

FIG. 8. Bacteria discharged in September, 1884, from a covered filter (broken line) and an open filter (solid line) in Berlin. The numbers upon the wavy lines indicate the number of bacteria per cubic centimeter. The numbers at the bottom indicate the days of the month. (After Wolffhugel and Piefke.)

Piefke then proceeds to a discussion on the relative advantages of covered and open filters, and shows that the open filters are more effective from a bacteriological point of view or at least that the out-put of bacteria from them is smaller. He gives a diagram (Fig. 8) showing these facts. The main objection to open filters is that in winter they cannot so readily be cleaned on account of the freezing of the sand, but Piefke claims that by selecting a warm "spell" for cleaning, it is quite possible (in Berlin) to avoid complications from this source, and the English experience certainly confirms this idea. It is to be remembered that the consumption of water is much smaller in winter, than in summer, and also that the life of the filter is correspondingly longer, owing to the absence of the more bulky vegetable growths of the summer. It seems probable that the greater bacterial efficiency of the open filters is due to their easier clogging which, of course, signifies a shorter "life."

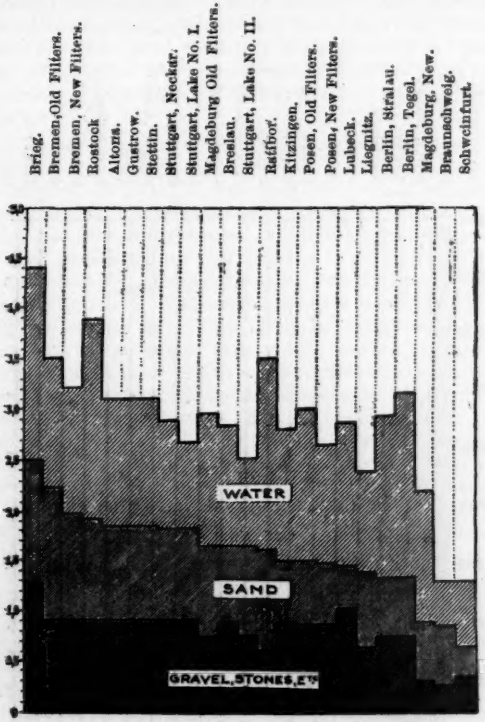

FIG. 9. *(After Kummel).* A diagram showing the depth of the filtering materials and the usual depth of unfiltered water upon the sand filters in use in certain cities and towns of Germany. The figures on the left indicate meters. It will be observed that the depth of the sand varies widely in different places.

As has been said above (p. 120) the addresses of Fraenkel and Piefke provoked much comment and their views met with considerable opposition. In the course of the debate Engineer Kummel, director of the water works at Altona, introduced some highly instructive diagrams which are here reproduced in Figs. 9 and 10.

More recently Piefke has repeated the experiments upon which his earlier conclusions were based and in such a manner as to meet all objections. The results entirely confirmed those of his previous experiments. There is no reason to doubt that a sand filter is not necessarily and under all circum-

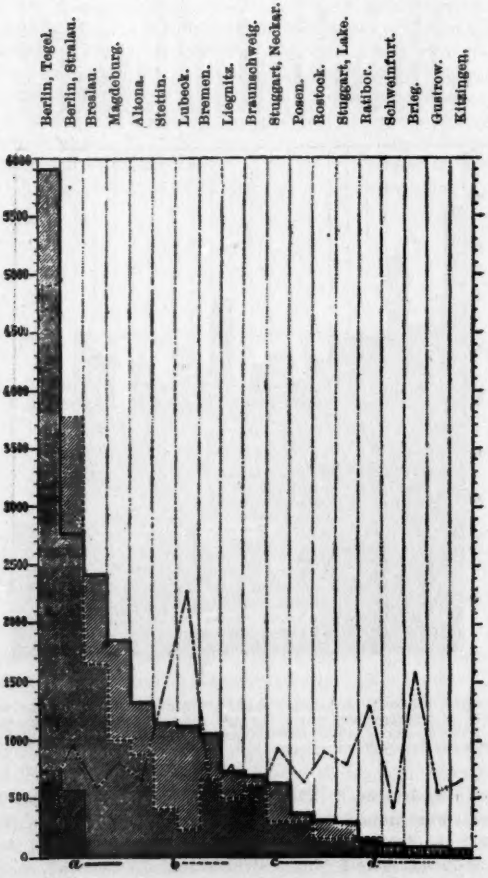

FIG. 10. (*After Kummel.*) The broad solid line [a] indicates one-tenth of the average number of cubic meters filtered daily [1 cu. metre=264.18 U. S. gallons.] The dotted line [b] indicates one-tenth of the square meters of filtering area. The narrower solid line [c] indicates one-tenth of the average area of filter surface cleaned daily. The broken line [d] indicates ten times the rate of filtration per hour in millimeters.

stances a germ proof apparatus. But it is equally plain that with proper management it may become germ tight and that even when not as carefully operated as it should be it is often very nearly germ proof. Its function as a sanitary safeguard is therefore of the highest importance, and that it has already attained great efficiency in this direction vital statistics abundantly prove.

I have already alluded to the fact that we owe to the State Board of Health of Massachusetts the first proof that bacteria may pass through a sand filter, and to Fraenkel and Piefke the first proof that bacteria may pass through during the continuous filtration of water. More recently the State Board of Health of Massachusetts has been experimenting at great length upon the removal of disease germs from the water of the Merrimac river as received at the Lawrence experiment station, both by intermittent and by continuous sand filtration. The results thus far obtained are highly satisfactory, and will soon be made public in the Report of the board. I may say, however, that it has already been found possible to remove all the germs of typhoid fever from the water of the Merrimac river by filtration through sand at a rate which readily places this means of purification within the reach of ordinary American cities. I would earnestly recommend to those interested in this subject that they fully inform themselves concerning the important researches in this direction now going on at the Lawrence experiment station of the State Board of Health of Massachusetts, under the direction of Hiram F. Mills, Esq., the distinguished hydraulic engineer, who is a member of the Board and Chairman of its Committee on on water supply and sewerage.

SAND FILTRATION OF THE WATER SUPPLY OF LONDON.

I have kept for the last the most important example of sand filtration in the world, namely, that of the public water supply of London. The water supply of London gradually became so objectionable that in 1852 it formed the subject of legislative interference which was destined to have a far-reaching influence not only upon London but upon the whole of Europe. In this year was passed the now well-known *Water Act*, which provided for a Metropolitan supply, granting the privileges of such supply to eight private companies, but requiring them to locate their intakes on the Thames above the influence of tidal flow and above the influence of London sewage, and prescribing effectual filtration. A portion of the *Act* runs as follows :

"From and after 31st August, 1855, every reservoir within a distance in a straight line of St. Paul's shall be roofed or otherwise covered over, except storage reservoirs for collecting the water before filtration, and except reservoirs for water used for street cleaning or fires, and not for domestic use.

"From and after 31st December, 1855, every company shall effectually filter all the water supplied by them within the metropolis for domestic use, excepting any water which may be pumped from wells into a covered reservoir or aqueduct without exposure to the atmosphere."

Instead of entering upon a detailed description of the London filters, which would require more space than I can command, I have ventured to reproduce in reduced fac simile one of the monthly reports upon the London Water Supply, taken at random, namely, that for May, 1892. This will be found in the *Appendix* to this paper, and upon pp. 4-7 of the *Appendix* is given a concise tabulated and comparative statement of the system, its extent, the depth of the filters, the amount of storage capacity, etc., etc., which has seemed to me peculiarly valuable inasmuch as it gives in great detail a description of the means by which the greatest, and probably the healthiest city in the world is served with drinking water, chiefly through sand filtration. The population supplied is now about 6,000,000, and the area of the sand filters employed for London is 109¾ acres.

It ought to be said that the water supply of London is still in the hands of the eight water companies to which it was given in 1852; and, furthermore, that extreme care is taken to secure, as far as possible, the cleanliness of the Thames by a special Board, the *Thames Conservancy Board*, which protects the purity of the water above the intake. By more recent acts these companies are required to submit the filtered water to the examination of an expert chemist employed by the Metropolis, though they also employ on their own part other chemists. For many years the chemist for the city has been Dr. E. Frankland, from whom a report appears in the fac simile, as does also one from the companies' present chemists, Messrs. Crookes and Odling.

I have introduced this (reduced) fac simile principally to show the great care and pains taken to secure for London a pure water supply. It naturally follows that the cost is also great. But I am of the opinion that the last place for economy should be in the matter of a supply of pure drinking water; and I believe that the time is at hand when American towns and cities must have pure drinking water at whatever cost. To accomplish this will require in many cases not only increased expenditure but also more expert administration.*

RESULTS OF SAND FILTRATION.

I have now given some account of the present theory and practice of sand filtration, and it only remains to consider its results. These are so obvious and so important as to challenge our attention and compel our admiration. The most convenient standard that we have for measuring the sanitary effect of a water supply is the mortality of the community from diarrhœal diseases. The reason for this is that these are naturally the diseases which contaminate sewage and which might be expected to travel in sewage-polluted drinking

*Those who wish to read further concerning the Water Supply of London may consult the following: *Quarterly Review*, 1892, p. 63. *Nineteenth Century*, 1892, p. 224. *Contemporary Review*, 1892, p. 26. *Fortnightly Review*, Vol. 36, p. 378. *The Monthly Reports on the Metropolitan Water Supply. The Annual Reports of the Local Government Board.* In the paper in the *Quarterly Review* [which contains much of value] further references will be found. I would also refer the reader upon the subject of filtration to *Kirkwood's* most valuable Report on the *Filtration of River Waters*, New York, 1869.

waters. Good examples of these diseases are Asiatic cholera and typhoid fever. The eruptive diseases such as measles, scarlet fever, and small pox, or the throat diseases such as diphtheria, cannot be expected to travel so readily in this way. Of all the diarrhœal diseases, typhoid fever is the best standard for our purposes, and I know of no disease which offers so good a measure of the sanitary condition of a community in respect to its water supply as this does. If now we compare the death rates from typhoid fever of such cities as London and Berlin having (in great part) river supplies filtered through sand, with those of American cities such as Philadelphia, Albany, Cincinnati, St. Louis, Lowell and Lawrence having similar supplies unfiltered, we shall find a very great difference in favor of filtration. Some of the results of such a comparison are given in a recent paper by Mr. Allen Hazen and myself, upon Typhoid Fever in Chicago.*

From a careful study of the figures and diagrams there given it will appear that London and Berlin compare very favorably with cities having great storage reservoirs, such as New York, and it is a fact that London has a death rate from this disease as low as that of many cities having unobjectionable supplies. I may also refer again to the results of Korosi's studies upon Buda-Pesth, (see above, p. 105), while Bertschinger has shown in his latest paper, referred to above, that with sand filtration of its water supply Zurich has become much less affected with typhoid fever. There is no reason to doubt that if Paris could subject the water of the Seine to sand filtration before delivering it as it occasionally does to the citizens for drinking purposes, many deaths in that city from typhoid fever might be avoided.

Postscript—One of the most striking phenomena of the recent cholera epidemic in Hamburg was the exemption of the closely connected city of Altona. Both are on the Elbe. Both use the Elbe as the source of their water supplies. But in Hamburg the only system of purification is the use (nominally) of settling basins. In Altona the water is purified by sand filtration. The Hamburg system is overworked and the water is scarcely allowed to settle at all. The death rate from typhoid fever has for years been high in Hamburg. During the recent epidemic of cholera Hamburg suffered severely while Altona, though very near it, on the same side and below it on the river, was virtually exempt.

Plate IX., (after Reincke) may serve to give a good idea of the remarkable instance furnished by Hamburg on the one hand, and Altona-Ottensen on the other. Fig. 1 shows the general situation of Hamburg, the main sewer outfalls of Hamburg and Altona, and the position of the intake of the Hamburg water works. Fig. 2 shows the intimate relations of Hamburg and Altona and also the location of the intake and the sand filters of Altona-Ottensen, some eight miles down the river at Blankenese. During the cholera epidemic of 1892, Hamburg with a population of 622,530 had 17,975 cases and 7,611 deaths from Asiatic cholera. Altona with a population of 143,000 had during the same period 562 cases and 328 deaths. The intake of the Hamburg water works is

*Engineering News, April 21, 1892.

about two miles above the city, but, it is said, not so far that the flood tide may not carry to it the sewage of Hamburg-Altona. The Elbe at Blankenese contains all the impurities present at the Hamburg intake, plus the sewage of Hamburg and Altona. Yet Altona suffered but little from cholera while Hamburg suffered severely. The Imperial Board of Health of Germany, in a recent publication, attributes the comparative exemption of Altona to the fact that its water supply was effectually protected throughout the epidemic by sand filtration.

On the other side of Hamburg from Altona lies the city of Wandsbeck (see Plate IX., Fig 1) with a population of about 20,000. Although it adjoins Hamburg it enjoyed an exemption similar to that of Altona, having had only 64 cases and 43 deaths from the cholera. Moreover, in the case of Wandsbeck and Altona there was every reason to suppose that the cases which did occur were imported from Hamburg, and not due to the local conditions. According to the Imperial Board of Health Wandsbeck is supplied with water, not from the Elbe, but from two inland lakes, the water from which is first subjected to thorough sand filtration and then delivered to the citizens. It is further stated that during the epidemic the sand filters of Altona were carefully watched and were worked at a low speed in order to secure complete protection against the disease.

It is cited by the same authority as a proof that the Hamburg water supply was infected that certain streets of Hamburg adjoining Altona were served by the Altona water works, and that these streets remained unaffected during the epidemic. So also did a portion of the garrison at Hamburg which used well water of good quality, while another portion supplied with the Hamburg water was attacked with cholera. As the very latest example of the beneficent sanitary results of sand filtration, the case of Altona is well worthy of the most serious consideration.

Those of our American cities, such as Chicago, Philadelphia, Albany, Lowell and Lawrence, which regularly supply to their citizens fecalized water, *i e*, water liable to contain bowel discharges, may reasonably feel no small anxiety after the sad experience of Hamburg with fecalized water in 1892.

APPENDIX

AND

PLATES.

REDUCED FAC-SIMILE OF

THE REPORT OF

THE METROPOLITAN WATER SUPPLY.

LONDON, ENGLAND.

MAY, 1892.

REPORT on the Condition of the Metropolitan Water Supply during the month of May 1892, by the Water Examiner appointed under the Metropolis Water Act, 1871.

The results of the Census of 1891 have shown that estimates of the increment of the population of Registration London for, at any rate, the later years of the decennium 1881–1891, based on the actual increments of the decennia 1861–71, 1871–81, which which have been used to some extent by the Metropolitan Water Companies in calculating the populations supplied by them, have been largely in excess of the actual increment. Since the publication of the preliminary census report and tables, the East London and Grand Junction Companies have furnished returns, in which large reductions in the figures of population supplied, as compared with earlier returns, have been made. Moreover evidence given in June 1892 before the Royal Commission on Water Supply has given rise to doubts in regard to the accuracy in other respects of the statistics of houses, population and water, supplied by some of the Companies to the Water Examiner. The subject is admittedly a difficult and complicated one, and even when the greatest care is exercised estimates can only be considered approximate. As the question is undergoing competent investigation the figures given in this report and the tables which follow must be considered to be, in the respects referred to, merely provisional and liable to considerable modification hereafter.

The Thames water at Hampton, Molesey, and Sunbury was in good condition during the whole of the month. At its highest point the water was 6 inches above, and at its lowest point 3 inches below the average summer level. The total rainfall during the month at West Molesey was 1·27 inches.

The average daily supply delivered from the Thames during the month was 98,925,329 gallons; from the Lee, 59,085,636 gallons; from springs and wells, 30,160,144 gallons; from ponds at Hampstead and Highgate, 287,417 gallons. The last is used for non-domestic purposes only. The daily total was, therefore, 188,458,526 gallons for a population aggregating 5,579,111, representing a daily consumption per head of 33·78 gallons for all purposes.

The relative proportions of the supplies from the above various sources were as follows:—

From the Thames	52·49 per cent.
„ „ Lee	31·35 „
„ springs and wells	16·01 „
„ ponds	0·15 „

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The following statement compares, in the case of each Company, the number of gallons per head per day supplied during the month, with the number supplied during the same month of the previous year:—

—	May.	
	1892.	1891.
Chelsea	30·90	35·91
East London	30·55	37·99
Grand Junction	47·49	47·70
Kent	30·73	29·07
Lambeth	29·06	28·86
New River	30·89	28·43
Southwark and Vauxhall	33·46	30·22
West Middlesex	30·79	31·07

The total number of houses supplied by the Water Companies during the month was 784,643, representing an increase of 1,275 supplies on the previous month.

The total supply divided by the number of houses shows a daily average of 240 gallons for each tenement.

In the following statement the per-centage of house supplies on the constant system in each Company's district on the 31st December 1891, and at the end of the month are compared:—

—	31st Dec. 1891.	31st May 1892.
Chelsea	23 per cent.	30 per cent.
East London	98 „	98 „
Grand Junction	75 „	73 „
Kent	56 „	57 „
Lambeth	53 „	55 „
New River	44 „	47 „
Southwark and Vauxhall	77 „	82 „
West Middlesex	43 „	46 „

The general result of the joint operation of the Companies and Authorities is shown by an increase during the month to the extent of 5,159 in the number of houses on constant supply, making the total 522,298, or about 67 per cent. of the total number of houses supplied.

The number of miles of streets containing water-pipes constantly charged in each Water Company's District within the Metropolis is as follows:—Chelsea, 80; East London, 185; Grand Junction, 85½; Kent, 158½; Lambeth, 171; New River, 308; Southwark and Vauxhall, 160; West Middlesex, 120½; Total 1,268 miles. Throughout this extent of streets, hydrants for fire purposes can be fixed.

A comparison of the number of miles of streets with mains constantly charged as entered in column 19 of the table following, with the number of public hydrants returned in column 20, will show what progress has been made within the Metropolis in meeting requirements for the more efficient protection of property from fire.

From the statement given by Dr. E. Frankland in his report on the analyses undertaken by him during the month on behalf of the Local Government Board, it appears that organic carbon was present in the samples of filtered water analysed by him, in proportions ranging for any unit of weight from 0·021 units to 0·126 units in every 100,000 units of the water. The chemists carrying out analyses for the Water Companies show by their results, which are recorded in the Appendix, proportions of organic carbon ranging from 0·048 units to 0·143 units in every 100,000 units of the water.

The proportions of brown tint in samples observed in a 2-foot tube, ascertained by their comparison with a standard tint of brown opposed to 20 mm. in thickness of blue tint, in the manner described in the report for October 1887, ranged from 1 mm. to 11 mm.

Referring to the report of the Companies' chemists, it will be seen that the water of the Southwark and Vauxhall Company showed the highest average amount of organic carbon, while that of the New River Company showed the lowest amount. The analyses made by Dr. Frankland on behalf of the Local Government Board

showed that the sample of water drawn from the mains of the Southwark and Vauxhall Company contained the highest proportion of organic carbon, and that of the Kent Company the lowest.

The water of the Southwark and Vauxhall Company exhibited the deepest average tint of brown.

In the following table the circumstances under which filtration was carried out during the month by each Company are compared, and the condition of the samples of water is also indicated.

Names of Companies.	Filtering Area per Million Gallons of Average Daily Supply.	Thickness of Sand.		Average Rate of Filtration per Square Foot per Hour.	Area of Filter Beds cleaned during the Month.
		Maximum.	Minimum.		
	Acres.	Ft. in.	Ft. in.	Gallons.	Acres.
Chelsea	0·68	4 0	4 0	1¾	2
East London	0·67	2 0	1 3	1½	29
Grand Junction	0·96	2 0	1 8	2 1/8	12¼
Lambeth	0·48	3 0	2 4	2½	8½
New River	0·80	2 3	1 5	2 1/8	19½
Southwark and Vauxhall	0·55	3 0	1 9	1½	14
West Middlesex	0·88	3 3	2 3	1¾	16½

The water delivered by the Chelsea, East London, Grand Junction, Lambeth, New River, and West Middlesex Companies, was found on examination to be effectually filtered. The water of the Southwark and Vauxhall Company at Battersea Works was also effectually filtered. The water issuing from the filters of this Company at Hampton on the 23rd of May contained suspended matter consisting mainly of vegetable fibre. Three-eighths of the available area of filters were thrown out of use for cleaning.

The following statement shows the number of days' supply represented by the capacity of the reservoirs for unfiltered water belonging to each Company:—

Chelsea	14·2
East London	13·7
Grand Junction	3·5
Lambeth	6·5
New River	5·1
Southwark and Vauxhall	2·5
West Middlesex	7·0

The relative positions here assigned to the Companies, in regard to their means of avoiding the introduction of flood-water to their filters, must, however, be qualified in certain cases to a considerable extent. The New River Company avails itself largely of well-water, and the River Lee, above its intake, is less fouled by floods than it is lower down the valley. The Southwark and Vauxhall, and the Grand Junction Companies, have the resource, during floods, of pumping from the gravel beds adjoining the Thames, and this is practically equivalent to an addition to their provision of storage-reservoirs. Nevertheless, under existing circumstances, turbid water must of necessity be sometimes admitted, and filters are then overtaxed. The Southwark and Vauxhall Company are engaged in the construction of additional filters at Hampton, and rapid progress is being made.

In the tabular statement which follows, details are given under 26 heads in reference to the subjects noted on above, as well as a number of others of interest which relate to the appliances and works of the Companies dealing with the Metropolitan Water Supply.

The Report of Dr. E. Frankland, F.R.S., on the analyses undertaken by him during the month, on behalf of the Local Government Board, will be found at page 8 of the Appendix to this Report; and is followed by a communication addressed to the Official Water Examiner by Messrs. Wm. Crookes, F.R.S., and Wm. Odling, M.B., F.R.S., with reference to the results of analyses undertaken by them at the instance of the Directors of the Seven Water Companies deriving their supplies from the Thames and the Lea. No analysis of the water supplied during the month has been furnished by the Kent Company.

Statistics of the Metropolitan Water Supply and Works

Name of the Company.	Intake.	Situation of Works.	Total Volume which may be drawn daily. — Gallons.	Average Daily Supply during the Month. — Gallons.	Approximate No. of hours when Water is laid on for domestic purposes.	Number of Houses, &c. supplied.	Number of Houses to which Water is laid on.	Estimated Population supplied, according to the Census of 1851.	Subsiding and Storage Reservoirs for Unfiltered Water.		
									No.	Area in Acres.	Available Capacity. — Gallons.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Chelsea Waterworks.	From the Thames at Hilton and Molesey.	Molesey	22,000,000	10,606,276	20 continuance of week.	36,258	10,272	288,195	4	40	140,000,000
		Scathing Wells	—	—		—	—	—	—	—	—
		Putney Heath	—	—		—	—	—	—	—	—
		Total of Chelsea Waterworks	22,000,000	10,606,276	—	36,258	10,272	288,195	4	40	140,000,000
East London Waterworks.	From the River Lea and Thames at Hackney, and Chalk Wells and Springs.		From Thames 10,000,000	From Thames 2,244,772	22 continuance of week.	172,627	170,210	1,174,089	—	—	—
		Walthamstow	From Lea, not restricted.	From Lea, 14,650,516		—	—	—	6	236	410,000,000
		Lee Bridge		From springs and wells 2,414,374		—	—	—	—	—	—
		Woodford Works	—	—		—	—	—	—	—	—
		Hackney	—	—		—	—	—	—	—	—
		Hanworth	—	—		—	—	—	1	3	5,000,000
		Hornsey Wood	—	—		—	—	—	—	—	—
		High Beech	—	—		—	—	—	—	—	—
		Chingford (well)	—	—		—	—	—	—	—	—
		Buckhurst Hill (water tower)	—	—		—	—	—	—	—	—
		Waltham Abbey	—	—		—	—	—	—	—	—
		Total of East London Waterworks	10,000,000	19,313,661	—	172,627	170,210	1,174,089	9	239	415,000,000
Grand Junction Waterworks.	From the Thames at Hampton.		25,500,000	12,612,092	15 to 15	97,771	42,609	293,270	—	—	—
		Hampton	—	—		—	—	—	2	12	51,000,000
		Kew	—	—		—	—	—	1	3	13,500,000
		Campden Hill	—	—		—	—	—	—	—	—
		Kilburn	—	—		—	—	—	—	—	—
		Hanger Hill, Ealing	—	—		—	—	—	—	—	—
		Ealing	—	—		—	—	—	—	—	—
		Total of Grand Junction Waterworks	25,500,000	12,612,092	—	97,771	42,609	293,270	3	17	64,500,000
Kent Waterworks.	From the Chalk Wells.		Not restricted.	15,272,397	20	77,410	44,270	400,000	None		
		New Cross	—	—		—	—	—			
		Deptford	—	—		—	—	—			
		Woolwich Common	—	—		—	—	—			
		Plumstead Common	—	—		—	—	—			
		Greenwich Park	—	—		—	—	—			
		Chislehurst	—	—		—	—	—			
		Shortlands	—	—		—	—	—			
		Crayford	—	—		—	—	—			
		Dover Road Shooters Hill	—	—		—	—	—			
		Farnborough	—	—		—	—	—			
		Dartford	—	—		—	—	—			
		West Wickham	—	—		—	—	—			
		Knockholt	—	—		—	—	—			
		Wilmington	—	—		—	—	—			
		Westerham	—	—		—	—	—			
		Total of Kent Waterworks	—	15,272,397	—	77,410	44,270	400,000	—	—	—
Lambeth Waterworks.	From the Thames at Molesey.		24,000,000	19,321,227	22 continuance of week.	96,363	51,321	669,333	—	—	—
		Molesey	—	—		—	—	—	2	20	122,000,000
		Long Ditton	—	—		—	—	—	2	1	2,000,000
		Brixton	—	—		—	—	—	—	—	—
		Streatham	—	—		—	—	—	—	—	—
		Balcrust	—	—		—	—	—	—	—	—
		Rockhill	—	—		—	—	—	—	—	—
		Coombe	—	—		—	—	—	—	—	—
		Norwood	—	—		—	—	—	—	—	—
		Total of Lambeth Waterworks	24,000,000	19,321,227	—	96,363	51,321	669,333	5	21	124,000,000

of the WATER COMPANIES for the Month of May 1892.

Storage Filtered Water Covered Reservoirs.		Engine Power.		Number of Miles of Water-pipes.	Number of Miles of Water-pipes in the Metropolis.	Number of Miles of Mains with Wells sunk periodically within the Metropolis.	Number of Miles Undipes and Fittings, and Fire-plugs fixed within the Metropolis.	Greatest lift by Steam Power.	Head of Pressure in the District supplied.		Filters.		
											Filter Beds.		Maximum Depth of Sand and other Materials.
No.	Capacity. — Gallons.	No.	Horse-Power.						Greatest.	Least.	No.	Area in Acres.	
13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.
—	—	—	—	225½ of which 122 1/2 are constantly charged.	208¼ of which 102 are constantly charged.	80	245 hydrants, and 4,207 fire-plugs.	Feet. 197	Feet. 115	Feet. 50	—	—	ft. in. Thames gravel 7 Shells, &c. - 0 3 Gravel - 3 3
—	—	—	—			—		—	—	—	—	—	
—	—	—	—			—		—	—	—	—	—	
—	—	13	1,150			—		—	—	—	7	6¼	
{ 1	10,000,000	—	—			—		—	—	—	—	—	
{ 2	1,000,000												
2	11,000,000	13	1,150	225½	208¼	80	—	—	—	—	7	6¼	3' 0"
—	—	—	—	942¾	443	125 Many streets with 2 mains, with 2 lines of pipes.	2,302 public hydrants, 225 private hydrants, and about 13,000 fire-plugs.	Feet. —	Feet. 250	Feet. 60	—	—	ft. in. Sand - 2 0
—	—	1	200						—	—	—	—	Hoggin - 0 6
—	—	14	2,710						—	—	25	24 1/2	Coarse gravel 1 0
2	2,000,000	2	150						—	—	—	—	
—	—	2	150						—	—	6	5	
2	2,500,000	2	630						—	—	—	—	
1	1,000,000	—	—						—	—	—	—	
1	2,500,000	—	—						—	—	—	—	
—	—	2	97						—	—	—	—	
1	70,000	—	—						—	—	—	—	
—	—	1	200					500	—	—	—	—	
7	13,070,000	20	4,107	942¾	443	125	—	—	—	—	31	29 3/4	3' 0"
—	—	—	—	438¼	199	85 1/4	195 hydrants and 3,278 fire-plugs, of which 1,569 are attached to pipes commonly charged.	Feet. 235	Feet. 155	Feet. 30	—	—	Old Pattern. ft. in. Harwich sand 2 6 Hoggin - 0 6 Fine gravel 0 9 Coarse gravel 0 9 Boulders - 1 0
1	2,500,000	12	1,774					—	—	—	7	9 1/4	
1	2,500,000	7	1,106					—	—	—	8	8 1/2	
3	10,000,000	3	522					—	—	—	—	—	New Pattern.
1	6,000,000	—	—					—	—	—	—	—	Sand - 2 0
{ 1	2,000,000 uncovered	—	—					—	—	—	—	—	Gravel - 0 6 Broken - 0 3
{ 1	30,000,000 uncovered	—	—					—	—	—	—	—	
8	52,000,000	22	3,412	438¼	199	85 1/4	—	—	—	—	15	17½	3' 0"
{ 1	1,750,000	—	—	385 1/2	212	126¼	1,767 hydrants on public roads. 672 in Government Establishments. 180 Private. 1,430 fire-plugs.	Feet. 600	Feet. 220	Feet. 50	None		
—	—	—	—					—	—	—			
2	2,000,000	2	252					—	—	—			
1	1,500,000	—	—					—	—	—			
2	350,000	1	63					—	—	—			
1	1,125,000	—	—					—	—	—			
1	450,000	—	—					—	—	—			
—	—	2	93					—	—	—			
—	—	2	126					—	—	—			
1	300,000	2	67					—	—	—			
1	1,400,000	4	252					—	—	—			
1	270,000	—	—					—	—	—			
1	750,000	—	—					—	—	—			
1	100,000	—	—					—	—	—			
—	—	1	130					—	—	—			
1	60,000	—	—					—	—	—			
15	10,335,000	23	1,663	385 1/2	212	126¼	—	—	—	—	—	—	—
—	—	—	—	632 3/4 of which 410 are constantly charged.	414 of which 212 are constantly charged.	171 Many streets with 2 and 3 and some with 6 lines of pipes.	2,032 Public hydrants. 257 hydrants for street watering. 119 Private hydrants & about 11,240 fire-plugs.	Feet. 250	Feet. 250 upon pumping mains. 150 upon serving mains.	Feet. 30	—	—	ft. in. Transcoured 2 0
—	—	2	100					—		—	—	—	Shells, &c. - 1 0
—	—	12	2,220					—		—	10	9 1/2	Coarse gravel 2 0
2	12,000,000	12	930					—		—	—	—	
2	7,500,000	—	—					—		—	—	—	
1	2,500,000	—	—					—		—	—	—	
1	625,000	—	—					—		—	—	—	
1	1,150,000	—	—					—		—	—	—	
1	5,000,000	—	—					—		—	—	—	
8	28,781,000	27	3,250	632 3/4	414	171	—	—	—	—	10	9 1/2	2' 0"

Statistics of the Metropolitan Water Supply and Works

Name of the Company	Intake.	Situation of Works.	*Total Volume which may be drawn daily. — Gallons.	Average Daily Supply during the Month. — Gallons.	Approximate per-centage used for domestic purposes.	Number of Supplies to Houses, &c. registered.	Number of Houses on the Mains supply.	Estimated Population supplied by the Water Companies	Subsiding and Storage Reservoirs for Unfiltered Water.		
									No.	Area in Acres.	Available Capacity. — Gallons.
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
New River -	From Chadwell Spring (the River Lea, and thirteen Chalk Wells.	- - - -	Not restricted	33,069,726 (Gross) of which 27,207,517 were drawn from Hampstead and Highgate wells, 2,923,795 from springs and wells, and 1,922,403 from the Lea.	25 gallons per head of domestic purposes.	122,227	72,355	1,205,000	–	–	–
		New River Head	–			–	–	–	1	3/4	700,000
		Clerkenwell Reservoir	–			–	–	–	–	–	–
		Stoke Newington	–			–	–	–	2	4.3 1/2	90,000,000
		Hornsey - -	–			–	–	–	2	8	3,500,000
		Campsbourne (well) -	–			–	–	–	–	–	–
		Holden Lane -	–			–	–	–	–	–	–
		Hornsey Lane -	–			–	–	–	–	–	–
		Highgate - -	–			–	–	–	15	30 3/4	29,000,000
		Hampstead -	–			–	–	–	2	3	900,000
		Camden Park Road -	–			–	–	–	–	–	–
		Aswell Red (well) -	–			–	–	–	–	–	–
		Aswell Hill (well) -	–			–	–	–	–	–	–
		Aswell March (well)	–			–	–	–	–	–	–
		Hoddesdon (well) -	–			–	–	–	–	–	–
		Broxbourne (well) -	–			–	–	–	–	–	–
		Turnford (well) -	–			–	–	–	–	–	–
		Cheshunt (well and reservoir) -	–			–	–	–	3	10 1/2	33,000,000
		Tottenham - -	–			–	–	–	–	–	–
		Southgate - -	–			–	–	–	–	–	–
		Botsells (well) -	–			–	–	–	–	–	–
		Orwell Hill - -	–			–	–	–	–	–	–
		Broad Mead (well) -	–			–	–	–	–	–	–
		Rye Common (well) -	–			–	–	–	–	–	–
		Hoe Lane (well) -	–			–	–	–	–	–	–
		Rickmansworth (well) -	–			–	–	–	–	–	–
		Bourne Hill - -	–			–	–	–	–	–	–
		Bush Hill - -	–			–	–	–	–	–	–
		Total of New River Company	–	33,069,000	–	122,227	72,355	1,205,000	29	90 1/2	260,100,000
Southwark and Vauxhall Waterworks.	From the Thames at Hampton.	- - - -	20,500,000	20,500,000	15 to 20 gallons per head of domestic purposes.	116,210	93,196	668,639	–	–	–
		Hampton - -	–	–		–	–	–	3	3 1/2	20,000,000
		Molesey - -	–	–		–	–	–	3	13	44,000,000
		Nunhead - -	–	–		–	–	–	–	–	–
		Total of Southwark and Vauxhall Waterworks -	20,500,000	20,500,000	–	116,210	93,196	668,639	6	17 1/2	64,000,000
West Middlesex Waterworks.	From the Thames at Hampton.	- - - -	20,500,000	19,022,627	15 gallons per head of domestic purposes.	71,323	56,631	403,593	–	–	–
		Hampton - -	–	–		–	–	–	–	–	–
		Kempton - -	–	–		–	–	–	–	–	–
		Barnes - -	–	–		–	–	–	6	27	117,500,000
		Campden Hill -	–	–		–	–	–	–	–	–
		Barrow Hill - -	–	–		–	–	–	–	–	–
		Finchley Road -	–	–		–	–	–	–	–	–
		Willesden - -	–	–		–	–	–	–	–	–
		Total of West Middlesex Waterworks	20,500,000	19,022,627	–	71,323	56,631	403,593	6	27	117,500,000
	From Thames - - -		120,000,000	92,592,520							
	Other Sources -		Not restricted	57,557,197							
GRAND TOTAL FOR THE METROPOLIS			–	150,150,520	–	709,963	522,520	3,275,111	53	400	1,229,100,000

* In December 1866 the Sources of the several Companies to draw water from the Thames were widened by agreement with the Conservators. The additional quantity of water to be taken daily by each of the Companies under the Agreement was, in the case of the Grand Junction, Lambeth, Southwark and Vauxhall, and West Middlesex, 4,500,000 gallons, and in the case of the Chelsea Company, 3,000,000 gallons.

of the WATER COMPANIES for the Month of May 1892.

Storage Filtered Water Covered Reservoirs		Engine Power.		Number of Miles of Water-pipes.	Number of Miles of Water-pipes in the Metropolis.	Number of Houses supplied with Water within the Metropolis.	Number of Street Hydrants within the Metropolis.	Constant lift by Steam Power.	Pressure in the District supplied.		Filters.		
									Greatest.	Least.	Filter Beds.		Maximum Depth of Sand and other Materials.
No.	Capacity. Gallons.	No.	Horse Power.								No.	Area in Acres.	
13.	14.	15.	16.	17.	18.	19.	20.	21.	22.	23.	24.	25.	26.
—	—	—	—	833 of which 696 are constantly charged.	746 of which 663 are constantly charged.	308	2,029 Public hydrants. 641 hydrants for street water-ing. 2,472 Private hydrants and about 13,800 fire-plugs.	Feet. 195	Feet. 235	Feet. 60	—	—	ft. in. Sand - 2 3 Gravel - 2 6 Surrounding concrete to-wards bottom.
—	—	2	200					—	—	—	2	2 1/4	
1	2,500,000	—	—					—	—	—	—	—	
—	—	6	1,250					—	—	—	2	2	
—	—	4	440					—	—	—	6	5 1/4	
—	—	2	120					—	—	—	—	—	
2	12,000,000	—	—					—	—	—	—	—	
1	3,000,000	2	135					—	—	—	—	—	
1	1,000,000	—	—					—	—	—	—	—	
1	500,000	—	—					—	—	—	—	—	
—	—	—	—					—	—	—	—	—	
—	—	1	50					—	—	—	—	—	
—	—	2	75					—	—	—	—	—	
—	—	2	70					—	—	—	—	—	
—	—	1	50					—	—	—	—	—	
—	—	3	120					—	—	—	—	—	
—	—	3	110					—	—	—	—	—	
—	—	1	20					—	—	—	—	—	
—	—	2	125					—	—	—	—	—	
1	1,000,000	—	—					—	—	—	—	—	
—	—	2	24					—	—	—	—	—	
2	12,000,000	—	—					—	—	—	—	—	
—	—	1	16					—	—	—	—	—	
—	—	2	200					—	—	—	—	—	
—	—	2	170					—	—	—	—	—	
—	—	3	210					—	—	—	—	—	
1	1,000,000	—	—					—	—	—	—	—	
1	60,000	—	—					—	—	—	—	—	
13	37,560,000	42	2,611	833	746	308	—	—	—	—	20	18 1/2	5 3
								Feet.	Feet.	Feet.			ft. in.
—	—	—	—	782	666	140	2,250 hydrants and 13,700 fire-plugs.	360	170	20	—	—	Harwich sand 3 0
—	—	6	1,200					—	—	—	2	2 1/4	Hoggin - 1 0
—	—	6	1,500					—	—	—	2	2 1/4	Fine gravel 0 9
4	12,000,000	2	100					—	—	—	—	—	Coarse gravel 0 9
4	12,000,000	14	2,800	782	666	140	—	—	—	—	12	12 1/2	5' 6"
								—	Feet.	Feet.	Feet.		ft. in.
—	—	—	—	4401/2 of which 3261/2 are constantly charged.	328 of which 177 1/4 are constantly charged.	1291/2	324 hydrants and about 2,000 fire-plugs.	—	—	—	—	—	Harwich sand 2 2
—	—	6	240					—	—	—	—	—	Barnes sand 1 0
—	—	9	1,625					195	190	130	—	—	Gravel - 2 2 Screened to different sizes and arranged in layers.
—	—	1	6					—	—	—	12	12	
1	3,272,000	—	—					—	—	—	—	—	
1	4,750,000	2	210					130	—	—	—	—	
1	2,100,000	—	—					—	—	—	—	—	
1	2,100,000	—	—					—	—	—	—	—	
6	12,422,000	17	2,261	4401/2	328	1291/2	—	—	—	—	12	12	5' 6"
19	216,282,000	133	23,130	4831	3451/4	1,268	16,693 hydrants.	—	—	—	107	102 1/2	—

A. DE C. SCOTT,
Water Examiner, Metropolis Water Act, 1871.
40, *Chancery Lane, W.C.*,
2nd July 1892.

To the Secretary,
Local Government Board.

APPENDIX.

Report of the Results of Analyses of the Metropolitan Water Supply undertaken during May 1892 by Dr. E. Frankland, F.R.S., on behalf of the Local Government Board.

Water-analysis Laboratory,
The Yews, Reigate,
6th June 1892.

SIR,

I HAVE to report to you the results of the chemical analysis and of the physical and bacteriological examination of the waters supplied to the inner, and portions of the outer, circle of the Metropolis during the month of May.

At the request of the Associated Metropolitan Water Companies, I have extended these monthly examinations to (*a*) the chemical and bacteriological condition of the raw river waters at the intakes of the various Companies, and (*b*) to the bacteriology of the water as it issues from the filter beds of each Company, and before it is pumped into the distributing mains.

I append, also, the results obtained in the analyses of the waters supplied to Birmingham and Glasgow by their respective Corporations. These analyses were made by Dr. Hill of Birmingham and Dr. Mills of Glasgow.

Taking the average amount of organic impurity contained in a given volume of the Kent Company's water during the nine years ending December 1876 as unity, the proportional amount contained in an equal volume of water supplied by each of the Metropolitan Water Companies and by the Tottenham Local Board of Health was:—Kent 0·6, New River and Colne Valley 1·1, Tottenham and East London (deep-well) 1·3, East London (river supply) 1·9, Chelsea, 2·1, West Middlesex and Grand Junction 2·2, Lambeth 2·3, and Southwark 2·5. The untreated river waters gave the following numbers:—New River cut 1·5, River Lea at East London Company's intake 2·9, and Thames at Hampton 3·4.

The water abstracted from the Thames by the Chelsea, West Middlesex, Southwark, Grand Junction, and Lambeth Companies was again, for river water, of a high degree of organic purity, being even superior, in this respect, to the samples drawn in April. It consisted, in fact, chiefly of spring water discharged from the chalk and oolite. It was efficiently filtered before delivery.

The water taken chiefly from the Lea by the New River Company again ranked with the deep-well waters in respect of organic purity, whilst that supplied from the same source, but lower down the stream, by the East London Company was superior to the best of the Thames waters. Both supplies were efficiently filtered.

The deep-well waters of the Kent, Colne Valley, and East London Companies, and of the Tottenham Local Board of Health, were of excellent quality for dietetic use, that of the Kent Company being especially distinguished for its very high degree of organic purity. The Colne Valley Company's water, having been softened before delivery, was rendered suitable for washing. All these waters were clear and bright without filtration.

Seen through a stratum two feet deep, the Kent, Colne Valley, Tottenham, and East London (deep-well) waters were clear and colourless, the New River clear and nearly colourless, whilst the remaining waters were clear and very pale yellow. The crude river waters presented the following appearances:—New River cut turbid and very pale yellow, the Lea at the East London Company's intake and the Thames at Hampton turbid and pale yellow.

The bacteriological examination of the waters as they left the filters of the various Companies, by Dr. Koch's process of gelatine plate-culture gave the following results. One cubic centimetre of each water collected on May 20th and 21st developed the following numbers of colonies of microbes:—West Middlesex and Lambeth 4, Southwark 8, New River and East London 10, Chelsea 12, and Grand Junction 24. Of the untreated river waters, one cubic centimetre of the water from the New River cut developed 158, the Thames at Hampton 631, and the Lea at the intake of the East London Company 4,526 colonies of microbes.

Dr. Hill, F.I.C., the Medical Officer of Health for Birmingham, reports that the water supplied to that city was "clear and of good colour, and the organic elements were less than they have been for a year."

Dr. Mills, F.R.S., of the Glasgow and West of Scotland Technical College, reports that the water supplied to that city from Loch Katrine was "light brown in colour and contained a little suspended matter."

I am, Sir,
Your obedient Servant,
(Signed) E. FRANKLAND.

To the Secretary,
Local Government Board,
Whitehall, S.W.

Table of the Results of the Chemical Analyses referred to in the foregoing Report.

All the numbers in columns 4, 5, 6, 7, 8, 9, 10, and 11 relate to 100,000 parts of the water.

The Table is to be read thus:—The Chelsea Company's water, collected on the 23rd May at the Horse Guards cab rank, had a temperature of 13°·3 C., 100,000 lbs. of it contained 2·6·16 lbs. of solid matter; the organic substances, constituting a portion of this matter, contained 1·0 lb. of carbon and ·0·16 lb. of nitrogen. The above quantity of water also contained no ammonia, but ·1·63 lb. of nitrogen in the form of nitrates and nitrites, whilst the total amount of combined nitrogen in every form was ·1·77 lb. The above weight of water also contained 1·6 lb. of chlorine, and 1·7·8 lbs. of carbonate of lime, or an equivalent quantity of other hardening or scale-destroying ingredients.

The numbers in the upright Table can be converted into grains per imperial gallon by multiplying them by 7, and then moving the decimal point one place to the left. The same operation transforms the hardness in the Table into degrees of hardness on Clark's scale.

Results of Analysis expressed in Parts per 100,000.

	Companies or Local Authorities.	Date and Place of Collection.	Temperature of Water when Collected. Centigrade Scale.	Total Solid Matter.	Organic Carbon.	Organic Nitrogen.	Ammonia.	Nitrogen as Nitrates and Nitrites.	Total combined Nitrogen.	Chlorine.	Total Hardness.
Inner Circle.	THAMES. (Unfiltered water)	May 24th. Grand Junction Co's. intake at Hampton.	14·0	28·16	·180	·026	·014	·153	·190	1·6	16·9
	Chelsea	May 23rd. Cab Rank, Horse Guards, Whitehall.	13·3	26·16	·110	·016	0	·163	·177	1·6	17·6
	West Middlesex	May 23rd. Cab Rank, Ridley House Street.	13·0	26·04	·113	·013	0	·164	·169	1·6	17·7
	Southwark	May 23rd. Cab Rank, "Shakespeare" Arms, Old Kent Road.	14·3	26·36	·126	·030	0	·161	·180	1·6	19·4
	Grand Junction	May 23rd. Cab Rank, Portman St., Oxford Street.	13·7	25·60	·113	·015	0	·168	·183	1·6	16·9
	Lambeth	May 23rd. Cab Rank, St. George's Road, Southwark.	14·6	27·28	·130	·016	0	·231	·251	1·9	19·4
	LEA. (Unfiltered water)	May 21st. New River Co's intake at Green Lanes.	14·5	27·28	·076	·013	·004	·218	·236	1·7	20·0
	New River	May 23rd. Cab Rank, Tottenham Court Road.	14·2	26·30	·080	·013	0	·194	·207	1·9	19·9
	(Unfiltered water)	May 21st. East London Co's. intake at Angel Road.	13·2	29·20	·140	·023	·013	·222	·256	1·9	21·5
	East London	May 23rd. Fire Brigade Station, Commercial Road, E.	13·7	28·90	·093	·043	0	·271	·290	2·0	20·6
	DEEP WELLS. Kent	May 23rd. Hill Lane, Deptford.	13·4	41·92	·021	·013	0	·475	·490	2·5	28·7
Outer Circle.	Colne Valley	May 23rd. Rigsby.	—	17·90	·053	·016	0	·270	·286	2·1	7·9
	Tottenham	May 21st. Tottenham.	—	23·24	·035	·019	·043	·036	·098	2·1	23·6
	East London	May 24th. Waltham Abbey Well.	—	27·44	·067	·013	0	trace	·013	2·1	17·7
Corporation of Birmingham*		May 6th. Rear of 31 Parade.	10·5	28·50	·039	·015	0	·206	·233	2·0	20·7
Corporation of Glasgow†		May 16th. Loch Katrine Water.	9·0	2·1	·203	·021	0	·0031	·0252	·72	·62
Column 1.		2	3	4	5	6	7	8	9	10	11

* Analysed by Dr. Alfred Hill, F.I.C., Medical Officer of Health and Analyst to the City.
† Analysed by Dr. R. F. Ellis, F.R.S., of the Glasgow and West of Scotland Technical College.
‡ Note.—The organic carbon in the East Water Co's. well at Orpington was erroneously printed as ·114 instead of ·013 in the water report for last month.

The subjoined communication, together with the succeeding three tables, have been received by the Metropolitan Water Examiner from the Chemists carrying out analyses on behalf of the Directors of the Water Companies deriving their supply from the Thames and the Lea :—

Sir, London, June 11th, 1892.

We submit herewith, at the request of the Directors, the results of our analyses of the 182 samples of water collected by us during the past month, at the several places and on the several days indicated, from the mains of the seven London Water Companies taking their supply from the Thames and Lea.

In Table I. we have recorded the analyses in detail of samples, one taken daily, from May 1st to May 31st inclusive. The purity of the water, in respect to organic matter, has been determined by the Oxygen and Combustion processes; and the results of our analyses by these methods are stated in Columns XIV. to XVIII.

We have recorded in Table II. the tint of the several samples of water, as determined by the colour-meter described in a previous report.

In Table III. we have recorded the oxygen required to oxidise the organic matter in all the samples submitted to analysis.

Of the 182 samples examined, three were found to be very slightly turbid; the remainder being clear, bright, and well filtered.

The character of the water supply to the Metropolis during the month of May was not found to differ appreciably from that manifested during the two or three months preceding. The proportion of organic matter present in the water—noticeably low throughout—was found to be just a little higher in the March supply than in that of February, but lower again in that of April, and still lower in that of the past month; this statement being applicable both to the Thames-derived and the Lea-derived supplies.

The following Table shows the smallness of the proportion of organic matter present in the Thames-derived supply, taken for illustration, and the successive but not important decrease in its proportion during the past three months. With the coming on, however, of any considerable rainfall, a corresponding unimportant increase in the proportion may be anticipated. The maximum proportion of organic carbon met with in any one of the 536 samples examined during the past three months, or 0·188 part in 100,000 parts of the water, corresponds as nearly as may be to a little over three-tenths of a grain of organic matter per gallon :—

——	Ratio of Brown to Blue Tint.	Oxygen required for Oxidation.	Organic Carbon per 100,000.	Organic Carbon per 100,000.
	Means.	Means.	Means.	Maxima.
March - - - -	8·6 : 20	·043	·144	·188
April - - - -	5·6 : 20	·033	·125	·147
May - - - - -	4·7 : 20	·029	·119	·143

We are, Sir,
Your obedient Servants,
WILLIAM CROOKES.
WILLIAM ODLING.

TABLE I.

Results of the Analysis of Daily Samples of the Water as supplied to the Metropolis, for the Month ending May 31st, 1892.

The results are stated in Grains per Imperial Gallon of 70,000 grains, except the Organic Carbon and Nitrogen, which are expressed both in Grains per Gallon and in parts per 100,000.

I. No.	II. Date of Collection.	III. Time of Collection.	IV. Company from the Mains of which the Sample was drawn.	V. Place where the Sample was drawn.	VI. Appearance.	VII. Matters in Suspension.	VIII. Ammonia.	IX. X. Chlorine.	XI. XII. Nitrogen as Nitric Acid (HNO_3).	XIII. Initial Hardness.	XIV. Oxygen required to Oxidize the Organic Matter. †	XV. Organic Carbon.	XVI. Organic Nitrogen.	XVII. Organic Carbon.	XVIII. Organic Nitrogen.
	1892.						Grains.	Grains.	Grains.	Degrees.	Grains.	Grains per Gallon.		Parts per 100,000.	
3501	May 6	3.30 p.m.	New River Co.	Tottenham Court Road	Clear	None	0·000	1·368 = 2·242	0·167 = 0·751	15·10°	0·016	0·040	0·010	0·057	0·015
3508	„ 14	6.35 „	New River Co.	Tottenham Court Road	Clear	None	0·000	1·296 = 2·124	0·168 = 0·846	13·80°	0·007	0·053	0·012	0·048	0·017
3515	„ 22	5.0 „	New River Co.	Tottenham Court Road	Clear	None	0·000	1·368 = 2·242	0·167 = 0·751	15·05°	0·012	0·048	0·011	0·069	0·016
3522	„ 31	5.30 „	New River Co.	Tottenham Court Road	Clear	None	0·000	1·368 = 2·242	0·177 = 0·796	15·05°	0·008	0·039	0·011	0·056	0·016
				Averages	—	—	0·000	1·350 = 2·212	0·175 = 0·786	15·05°	0·011	0·040	0·011	0·057	0·016
3502	„ 7	8.30 „	East London Co.	Cambridge Road	Clear	None	0·000	1·512 = 2·478	0·177 = 0·796	16·25°	0·020	0·071	0·016	0·101	0·023
3509	„ 16	9.20 „	East London Co.	Cambridge Road	Clear	None	0·000	1·512 = 2·478	0·177 = 0·796	15·30°	0·021	0·077	0·021	0·110	0·030
3516	„ 24	7.30 „	East London Co.	Cambridge Road	Clear	None	0·000	1·519 = 2·478	0·136 = 0·703	15·30°	0·023	0·094	0·021	0·134	0·030
				Averages	—	—	0·000	1·519 = 2·478	0·170 = 0·765	15·78°	0·024	0·081	0·019	0·115	0·027
3503	„ 9	7.20 „	Chelsea Co.	Horse Guards	Clear	None	0·000	1·296 = 2·124	0·136 = 0·703	13·05°	0·023	0·070	0·019	0·100	0·027
3510	„ 17	6.30 „	Chelsea Co.	Horse Guards	Clear	None	0·000	1·296 = 2·124	0·136 = 0·607	13·05°	0·023	0·069	0·016	0·099	0·023
3517	„ 25	6.25 „	Chelsea Co.	Horse Guards	Clear	None	0·000	1·296 = 2·124	0·126 = 0·703	14·84°	0·026	0·089	0·021	0·140	0·030
				Averages	—	—	0·000	1·296 = 2·124	0·149 = 0·670	14·86°	0·025	0·079	0·019	0·113	0·027
3497	„ 3	6.0 „	West Middlesex Co.	Portland Road	Clear	None	0·000	1·296 = 2·124	0·136 = 0·703	16·10°	0·030	0·091	0·017	0·130	0·024
3504	„ 10	6.0 „	West Middlesex Co.	Portland Road	Clear	None	0·000	1·296 = 2·124	0·146 = 0·657	15·68°	0·028	0·087	0·020	0·124	0·029
3511	„ 18	6.0 „	West Middlesex Co.	Portland Road	Clear	None	0·000	1·296 = 2·124	0·146 = 0·657	15·47°	0·027	0·075	0·014	0·108	0·020
3518	„ 26	6.15 „	West Middlesex Co.	Portland Road	Clear	None	0·000	1·296 = 2·124	0·135 = 0·607	14·84°	0·026	0·069	0·015	0·123	0·026
				Averages	—	—	0·000	1·296 = 2·124	0·146 = 0·656	15·52°	0·027	0·085	0·017	0·122	0·025
3498	„ 3	7.10 „	Lambeth Co.	St. George's Road, Southwark	Clear	None	0·000	1·368 = 2·242	0·146 = 0·657	14·84°	0·020	0·085	0·019	0·122	0·028
3505	„ 11	7.30 „	Lambeth Co.	St. George's Road, Southwark	Clear	None	0·000	1·296 = 2·124	0·177 = 0·796	15·68°	0·024	0·084	0·019	0·120	0·023
3512	„ 19	7.30 „	Lambeth Co.	St. George's Road, Southwark	Clear	None	0·000	1·296 = 2·124	0·167 = 0·751	14·84°	0·025	0·073	0·023	0·104	0·033
3519	„ 27	6.45 „	Lambeth Co.	St. George's Road, Southwark	Clear	None	0·000	1·512 = 2·478	0·177 = 0·796	14·84°	0·022	0·089	0·016	0·126	0·022
				Averages	—	—	0·000	1·368 = 2·242	0·167 = 0·750	15·05°	0·020	0·083	0·019	0·118	0·026
3499	„ 4	6.30 „	Grand Junction Co.	Uxbridge Road	Clear	None	0·000	1·296 = 2·124	0·167 = 0·751	14·84°	0·020	0·080	0·016	0·114	0·026
3506	„ 12	6.30 „	Grand Junction Co.	Uxbridge Road	Clear	None	0·000	1·296 = 2·124	0·156 = 0·703	14·84°	0·024	0·100	0·024	0·143	0·031
3513	„ 20	7.5 „	Grand Junction Co.	Uxbridge Road	Clear	None	0·000	1·368 = 2·242	0·146 = 0·657	14·84°	0·031	0·064	0·013	0·091	0·021
3520	„ 28	6.0 „	Grand Junction Co.	Uxbridge Road	Clear	None	0·000	1·368 = 2·242	0·135 = 0·607	14·84°	0·032	0·065	0·020	0·121	0·029
				Averages	—	—	0·000	1·332 = 2·183	0·151 = 0·679	14·84°	0·029	0·083	0·019	0·117	0·026
3500	„ 5	7.45 „	Southwark and Vauxhall Co.	St. George's Church, Borough	Clear	None	0·000	1·296 = 2·124	0·156 = 0·702	15·68°	0·020	0·094	0·021	0·135	0·030
3507	„ 13	8.5 „	Southwark and Vauxhall Co.	St. George's Church, Borough	Clear	None	0·000	1·296 = 2·124	0·136 = 0·703	14·42°	0·027	0·070	0·022	0·100	0·031
3514	„ 21	7.30 „	Southwark and Vauxhall Co.	St. George's Church, Borough	Clear	None	0·000	1·296 = 2·124	0·135 = 0·607	15·05°	0·023	0·100	0·019	0·143	0·027
3521	„ 30	7.0 „	Southwark and Vauxhall Co.	St. George's Church, Borough	Clear	None	0·000	1·296 = 2·124	0·135 = 0·607	14·84°	0·040	0·094	0·023	0·134	0·032
				Averages	—	—	0·000	1·296 = 2·124	0·145 = 0·654	15·00°	0·034	0·089	0·021	0·128	0·030

* *See* Table II.

† The amount of oxygen is determined by a standard solution of potassic permanganate acting in the cold for three hours.

TABLE II.

Showing the Appearance and Condition of the Water as regards Turbidity, and the Colour determined by Standard Tints in a Two-Foot Tube, of the Water supplied to the Metropolis, from the Mains of the several Companies, for the Month ending May 31st, 1892.

No.	Date of Collection.	New River Company.		East London Company.		Chelsea Company.		West Middlesex Company.		Lambeth Company.		Grand Junction Company.		Southwark and Vauxhall Company.	
		Appearance.	Colour.	Appearance.	Colour.	Appearance.	Colour.	Appearance.	Colour.	Appearance.	Colour.	Appearance.	Colour.	Appearance.	Colour.
	1892.		Brown : Blue		Brown : Blue		Brown : Blue		Brown : Blue		Brown : Blue		Brown : Blue		Brown : Blue
2497	May 2	C.	1 : 20	C.	4 : 20	C.	4 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20
2498	" 3	C.	1 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20
2499	" 4	C.	1 : 20	C.	4 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20
2500	" 5	C.	1 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20
2501	" 6	C.	2 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20	C.	4 : 20	C.	5 : 20
2502	" 7	C.	2 : 20	C.	4 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	7 : 20
2503	" 9	C.	1 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	6 : 20
2504	" 10	C.	1 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20
2505	" 11	C.	1 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20
2506	" 13	C.	1 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20
2507	" 13	C.	1 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20
2508	" 14	C.	1 : 20	V.&T.	11 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20
2509	" 15	C.	1 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20	C.	4 : 20	C.	4 : 20
2510	" 17	C.	2 : 20	C.	6 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	7 : 20	C.	7 : 20
2511	" 18	C.	2 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	7 : 20	V.&T.	10 : 20
2512	" 19	C.	1 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20	C.	6 : 20	C.	7 : 20
2513	" 20	C.	2 : 20	C.	6 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	6 : 20
2514	" 21	C.	2 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	6 : 20	C.	6 : 20
2515	" 25	C.	1 : 20	C.	4 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	7 : 20	C.	6 : 20
2516	" 24	C.	1 : 20	C.	4 : 20	C.	4 : 20	C.	4 : 20	C.	5 : 20	C.	6 : 20	C.	7 : 20
2517	" 25	C.	1 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	4 : 20	C.	6 : 20
2518	" 26	C.	1 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20
2519	" 27	C.	2 : 20	C.	5 : 20	C.	4 : 20	C.	5 : 20	C.	5 : 20	C.	4 : 20	C.	7 : 20
2520	" 28	C.	2 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	5 : 20	C.	9 : 20
2521	" 29	C.	2 : 20	V.&T.	6 : 20	C.	5 : 20	C.	5 : 20	C.	7 : 20	C.	6 : 20	C.	8 : 20
2522	" 31	C.	1 : 20	C.	5 : 20	C.	4 : 20	C.	4 : 20	C.	5 : 20	C.	7 : 20	C.	10 : 20
	Average	—	1·3 : 20	—	4·2 : 20	—	5·4 : 20	—	5·9 : 20	—	5·0 : 20	—	5·1 : 20	—	6·0 : 20

Degrees of Turbidity.

Note.—
C. = Clear.
V. & T. = Very slightly turbid.
S. T. = Slightly turbid.
T. = Turbid.

Colour Test.

Note.—The ratios show the proportions of Brown to Blue in the water; the figures representing millimetres in thickness of the respective standard solutions. Thus 10 : 20 would express a colour composed of 10 millimetres of Brown solution superposed on 20 millimetres of Blue solution.

TABLE III.

SHOWING the QUANTITY of OXYGEN in Grains per Gallon required to OXIDISE the ORGANIC MATTER, in DAILY SAMPLES of the WATER as supplied to the METROPOLIS, from the MAINS of the COMPANIES, during the Month ending May 31st, 1892.

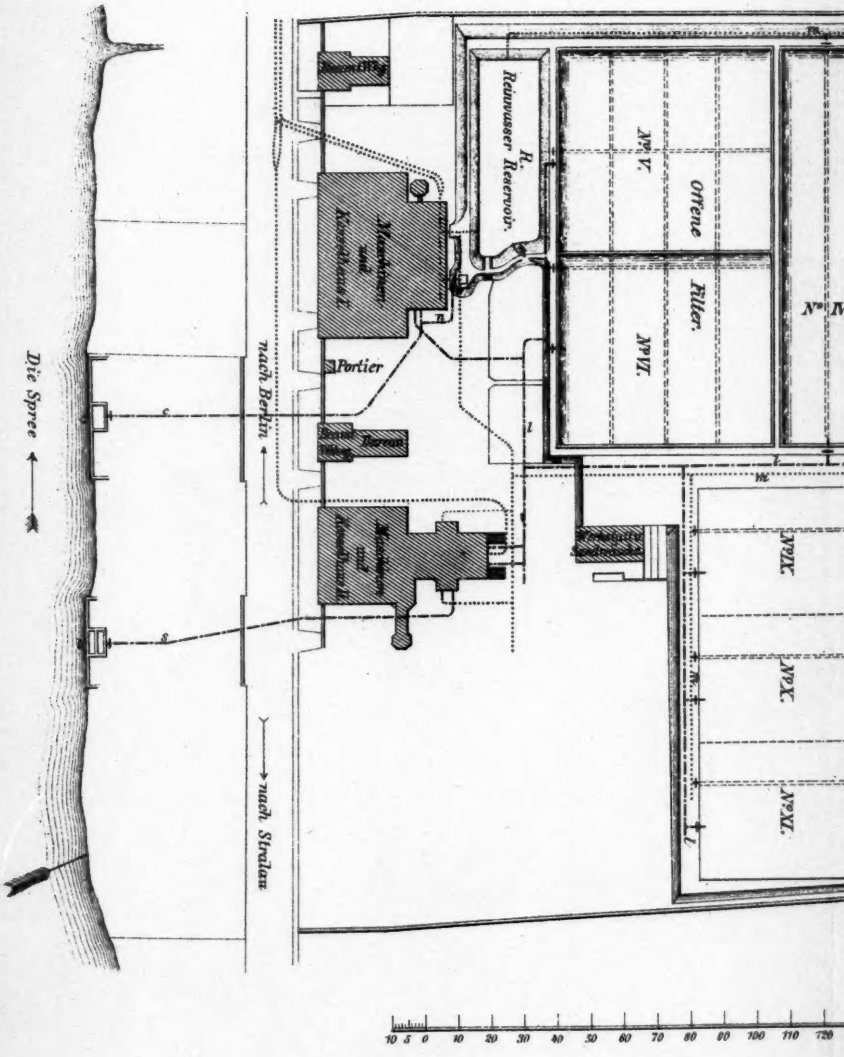
No.	Date of Collection.	New River Company.	East London Company.	Chelsea Company.	West Middlesex Company.	Lambeth Company.	Grand Junction Company.	Southwark and Vauxhall Company.
		Oxygen required by Organic Matter.	Oxygen required by Organic Matter.	Oxygen required by Organic Matter.	Oxygen required by Organic Matter.	Oxygen required by Organic Matter.	Oxygen required by Organic Matter.	Oxygen required by Organic Matter.
	1892.	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.	Grains.
3497	May 2	0·011	0·033	0·030	0·030	0·033	0·033	0·033
3498	„ 3	0·011	0·030	0·030	0·030	0·030	0·026	0·026
3499	„ 4	0·011	0·023	0·026	0·026	0·030	0·030	0·030
3500	„ 5	0·015	0·023	0·026	0·026	0·030	0·026	0·030
3501	„ 6	0·016	0·024	0·028	0·023	0·028	0·032	0·032
3502	„ 7	0·012	0·020	0·024	0·024	0·028	0·028	0·028
3503	„ 9	0·008	0·023	0·023	0·019	0·031	0·027	0·035
3504	„ 10	0·008	0·023	0·023	0·023	0·027	0·027	0·035
3505	„ 11	0·004	0·020	0·024	0·024	0·024	0·028	0·028
3506	„ 12	0·004	0·024	0·024	0·024	0·024	0·024	0·024
3507	„ 13	0·007	0·023	0·019	0·023	0·023	0·035	0·027
3508	„ 14	0·007	0·027	0·027	0·027	0·027	0·031	0·027
3509	„ 16	0·015	0·031	0·019	0·039	0·039	0·039	0·039
3510	„ 17	0·015	0·029	0·023	0·039	0·040	0·039	0·039
3511	„ 18	0·011	0·023	0·011	0·027	0·031	0·035	0·035
3512	„ 19	0·011	0·019	0·011	0·027	0·035	0·031	0·035
3513	„ 20	0·012	0·023	0·027	0·027	0·031	0·031	0·035
3514	„ 21	0·011	0·027	0·035	0·027	0·031	0·031	0·039
3515	„ 23	0·012	0·028	0·032	0·036	0·040	0·040	0·036
3516	„ 24	0·016	0·028	0·032	0·036	0·040	0·040	0·040
3517	„ 25	0·008	0·028	0·028	0·024	0·036	0·032	0·032
3518	„ 26	0·008	0·024	0·028	0·028	0·036	0·028	0·032
3519	„ 27	0·012	0·024	0·024	0·028	0·032	0·032	0·032
3520	„ 28	0·012	0·024	0·024	0·028	0·032	0·032	0·032
3521	„ 30	0·012	0·020	0·024	0·024	0·032	0·036	0·040
3522	„ 31	0·008	0·020	0 020	0·024	0·032	0·032	0·036
	Average	0·010	0·024	0·024	0·027	0·032	0·032	0·033

SITUATION AND NUMBER OF THE CHALK WELLS OF THE KENT COMPANY.

Place.	No.
Deptford	3
Plumstead	1
Crayford	3
Shorlands	2
Farnborough	2
Wilmington	1
Total	12

The water supplied by this Company is taken from Chalk Wells, and is therefore not filtered; it is invariably clear and bright.

UNIVERSITY



PLAN SHOWING THE LOCATION OF THE BE

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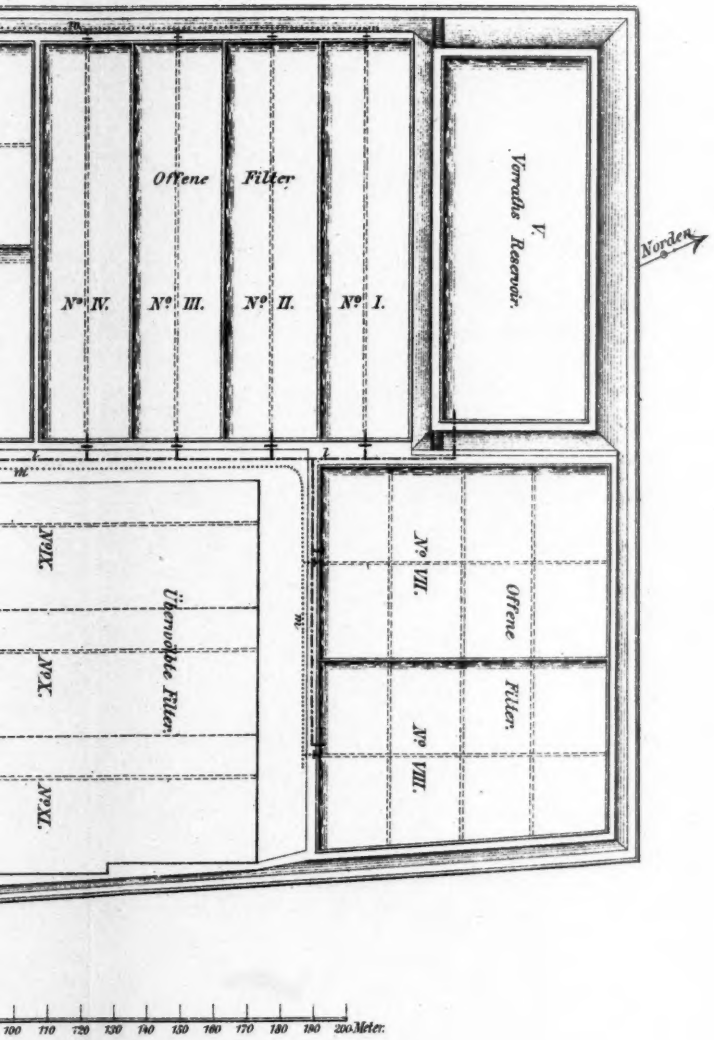

THE BERLIN-STRALAU WATER WORKS.

R PIEFKE.)

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Fig. 1.
Ansicht.

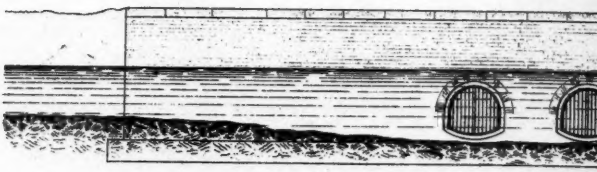

Fig. 2.
Schnitt C-D.

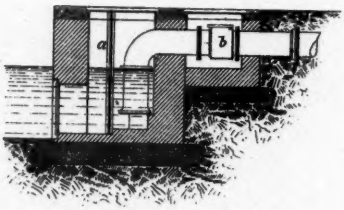

Fig. 3.
Schnitt A-B.

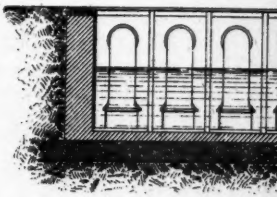

Fig. 5.
Grundriss.

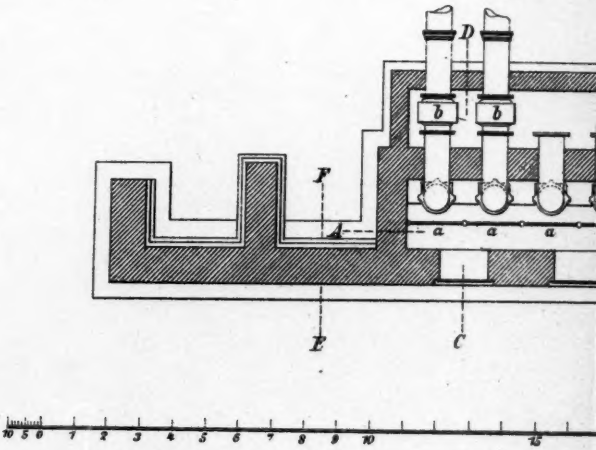

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Fig.1.
Ansicht.

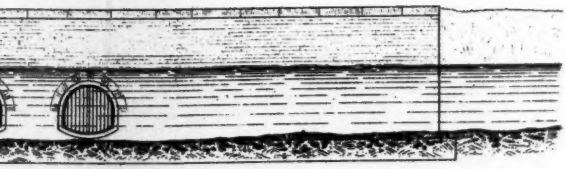

Fig.3.
hnitt A-B.

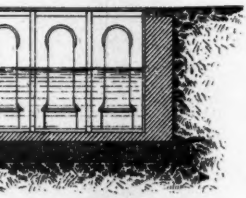

Fig.4.
Schnitt E-F.

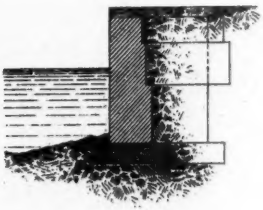

Fig.5.
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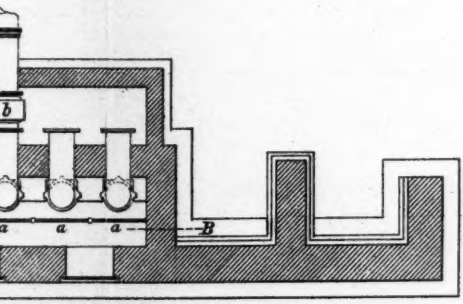

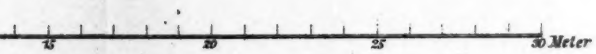

ERLIN-STRALAU WATER WORKS.
(AFTER PIEFKE.)

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Fig. 1.

Längsschnitt durch den Reinwasser

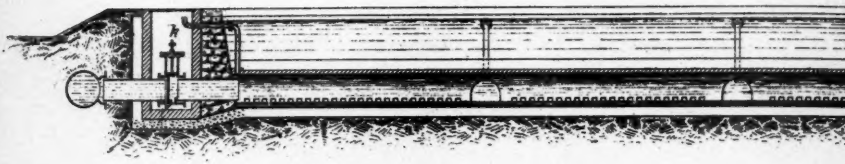


Fig. 2.

Querschnitt durch den Reinwasserkanal u

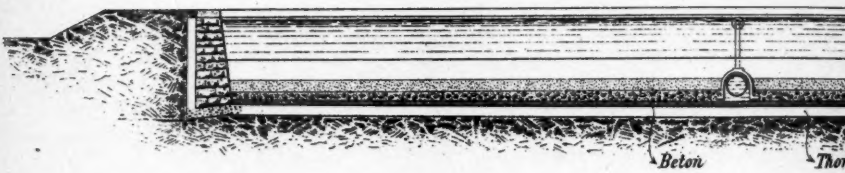


Fig. 3.

Schnitt durch das Zuflussrohr.

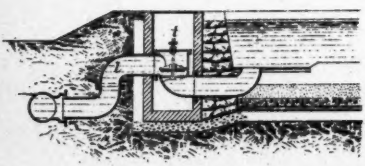


Fig. 4.

Ansicht des Sandhahns.

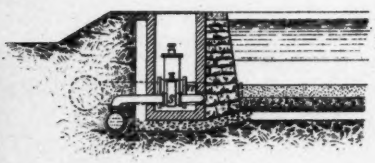
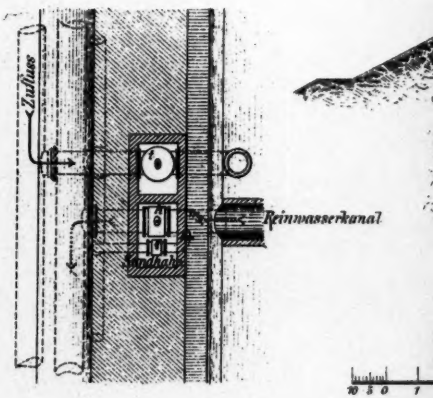


Fig. 5.

Aufsicht.

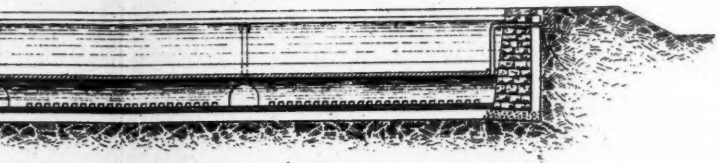


SECTIONS OF OPEN AND COVERED SAND-FILTERS.

(AFTER PIEFKE.)

1.

Reinwasserkanal.



2.

sserkanal und das Überlaufrohr.

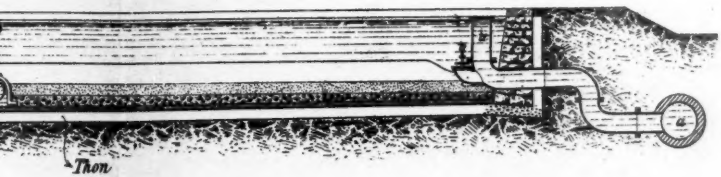
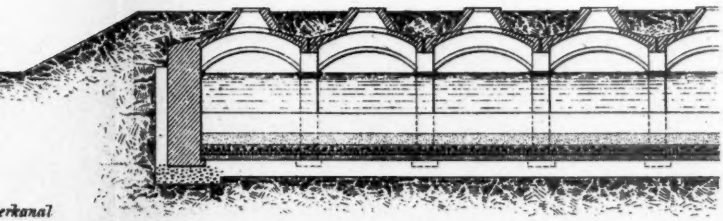
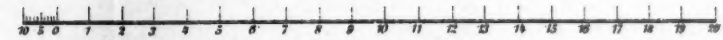


Fig. 6.

Schnitt durch ein überwölbtes Filter.



erkanal



FILTERS. – BERLIN-STRALAU · WATER WORKS.

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Fig. 1.
Querschnitt

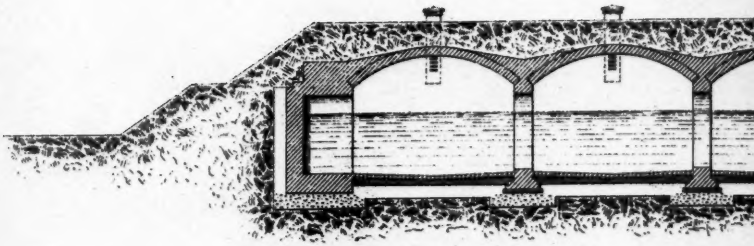
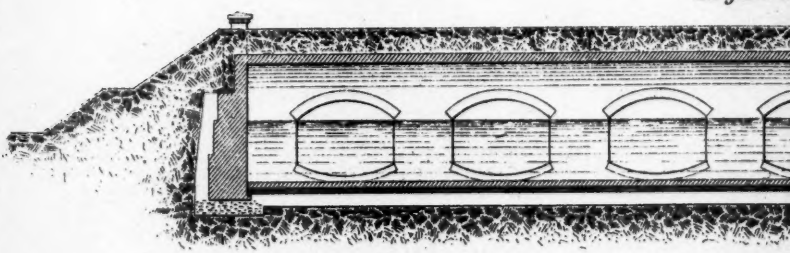
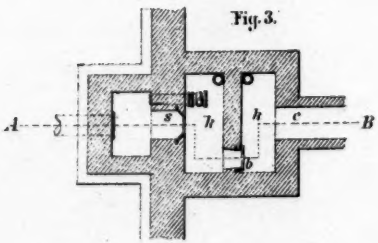


Fig. 2.
Längsschnit



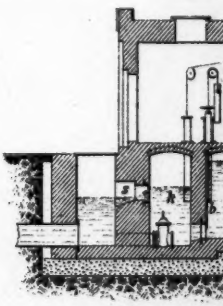
Vorkammer für die Filte

Fig. 3.

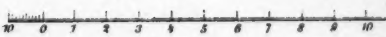


Grundriss.

Fig. 4.



Schnitt A-B



THE RESERVOIR FOR FILTERED WATER AT
AND GILL REGULATOR AT THE
(AFTER P

Fig. 1.
Querschnitt.

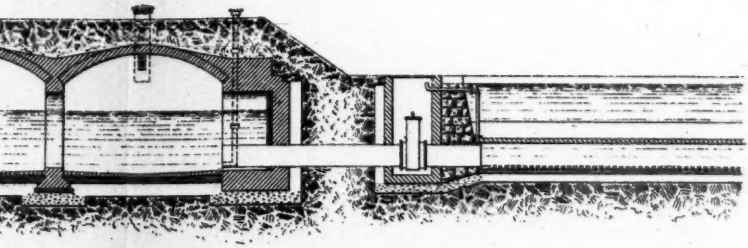
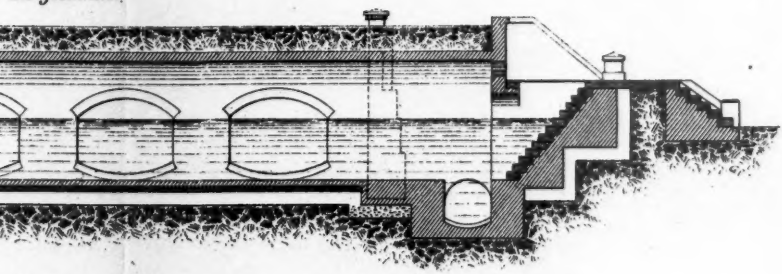
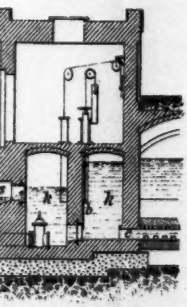


Fig. 2.
Längsschnitt.



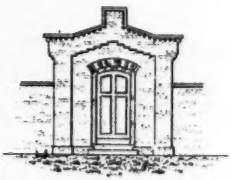
für die Filter der Station Tegel.

Fig. 4.



Schnitt A-B.

Fig. 5.



Ansicht.

TER AT BERLIN-STRALAU AND THE GATE-HOUSE
AT THE BERLIN-TEGEL WATER WORKS.
(AFTER PIEFKE.)

HELIOTYPE PRINTING CO. BOSTON

Fig. 1.

Grundriss.

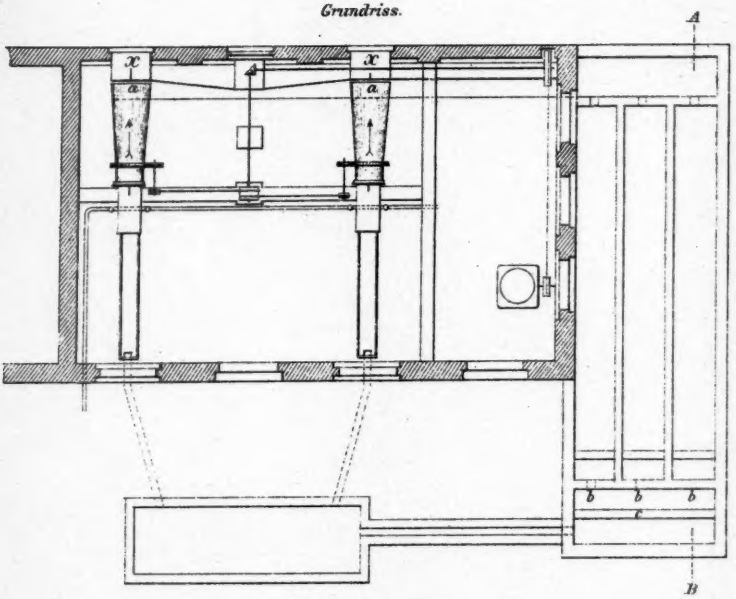
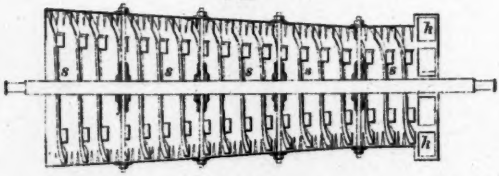
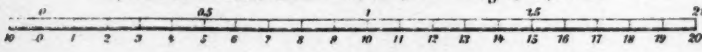


Fig. 3.

Sandwaschtrommel
1:25



Massstab für die Sandwäsche 1:200, für die Centrifugalpumpe 1:20.



THE SAND-WASHING PLANT OF THE

(AFTER P

Fig. 2.
Querschnitt.

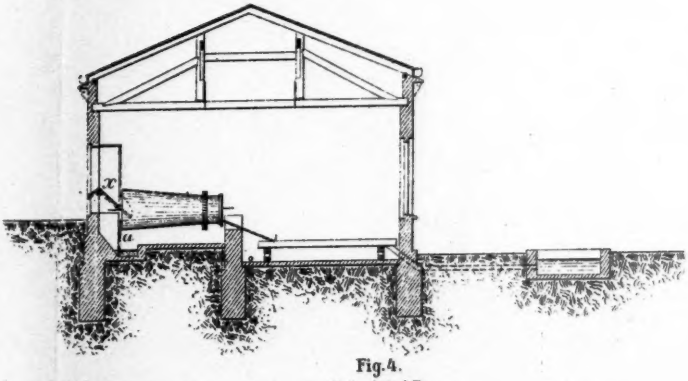
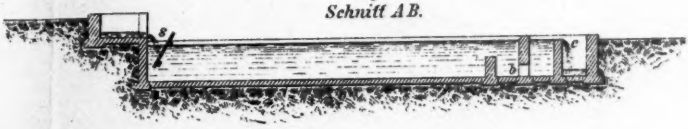


Fig. 4.
Schnitt A B.



Centrifugalpumpe.

Fig. 3.
Querschnitt.

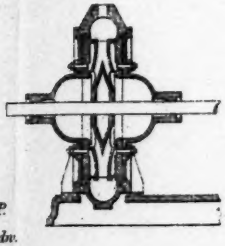
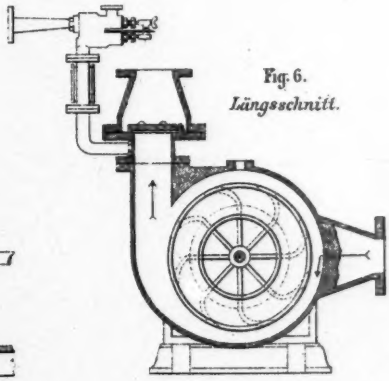


Fig. 6.
Längsschnitt.



2 m. für die Centr. P.
30 m. für die Sandw.

OF THE BERLIN-STRALAU WATER WORKS.
(AFTER PIEFKE.)

HELIOTYPE PRINTING CO., BOSTON.

BE UND BAUWESEN.

Wasserwerke der Stadt Berlin
am Tegeler-See.

Ueberwölbte Filter.
(Ausführung 1885.)

Grundriss nach k-m.
1:300.

Lageplan

Filter XII

Schnitt a-b.

Schnitt g-h.

N.N. Die Ordinaten sind
Berl. Dammühlen

Maassstab 1:150.

Maassstab 1:200 für die Grundriss.

N.

Tegeler See

Teich

Maschinen-Haus

Schornstein

Reservoirs I II

Reservoirs III IV

Ueberwölbte Filter I II III IV

Ueberwölbte Filter V VI VII VIII IX X

Sandwäsche

Beamtenwohnh. 2

Stall

nach Dalldorf

Vorder-Ansicht.

Schnitt e - f.

Sand

Thonboden

Schnitt i - k.

Sand

Thonboden

Maassstab 1:2000 für den Lageplan.

Druck v. F. C. GLASER, Berlin SW. Lindenstr. 33

Fig. 1.
A, B, C, Outfalls of main sew
Hamburg-Altona.
G Intake of Hamburg Water
Numbers show population in 18
Fig 2. D. Blankenese. Intake
sand-filters, Altona-Ottensen Water Wo

PLATE IX. *(after Reincke.)*

Fig. 2.

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ERRATA.

The electrotypes for plates 3, 4 and 5, accompanying the paper on the New London High Service were kindly loaned by the *Engineering News*, credit in the proper place being omitted by an oversight.

In the paper on The Purification of Drinking Water, by Prof. Wm. T. Sedgwick, published in the December number, Plate VIII. was omitted through a failure of the parties making the plate to deliver it in time for publication. The plate is included in the present number.

The editors offer an apology for the discolored edges of a few sheets in the present number, due to a fire in the bindery.